Ethan Eldred
ethaneldred@gmail.com
OMPRD 507
Architectural, Acoustic, and Audio System Design
Berklee College of Music
Professor John Storyk

Assignment 11: Final Project

Section 1: Program, Site, and Design Criteria

Program

My current home studio is primarily for my own use and serves multiple purposes. A primary use, aside from my studio work, is as a normal living room, with space for television viewing and other relaxation. I use the space for producing, recording, and mixing my own music and sound designs for theatre, media, and art installations. My genre of choice for music is Americana and electronica, mixed in varying proportions. Folk music has been around since the dawn of music, and we're only at the dawn of the age of electronic music now. I expect both genres to carry on with or without me for some time, with or without me, and will grow as music production becomes more and more decentralized. My sound design/art taste follows along the same lines, with mixtures of voices, natural and found sound from life, and digital and warped electronic sounds. Like folk music, theatre and storytelling are ancient and not going anywhere.

While my studio is primarily for my own projects, on occasion I'll also host a friend or two for a recording or mixing session, and only very rarely more than one other artist at a time. On the rare occasion that I need to host a larger group or have more standby space, I usually move to another location. I have my equipment set up for portability in the event that I need to transport it, and will continue to do so as I modify my space. Even with collaborators, work is mostly confined to the main space. I have explored the idea of using the adjacent home theater room for dual purposes as an ad-hoc isolation room, but even in the best case, isolation between the two rooms is minimal, as there is no option for sightline and cable paths other than through or under the door. This phase of the design focuses on the primary listening position and secondarily on the recording area of the main room.

A primary goal in my design is for as much of my studio setup as possible, to be suitable for temporary installation and portability to other sites. This serves my typical work life, which can involve remote/site work, and is also necessary due to site considerations and the temporary nature of my current space. The apartment includes several large furniture pieces that cannot be removed from the apartment, and so must be incorporated in any design, either in the living room studio, or by making space in another room.

Perhaps most importantly, while there is other space for relaxing in the apartment when studio work is happening, the room must continue to function as a comfortable living room. Any solutions should enhance rather than detract from the room's aesthetic appeal.

Site Considerations

My studio usage and design is limited by its context: my furnished rental apartment in a triplex house. Any and all domestic activities, including cooking, cleaning, and the use of large appliances, occur in adjoining rooms within my apartment, as well as in the two neighboring apartments.

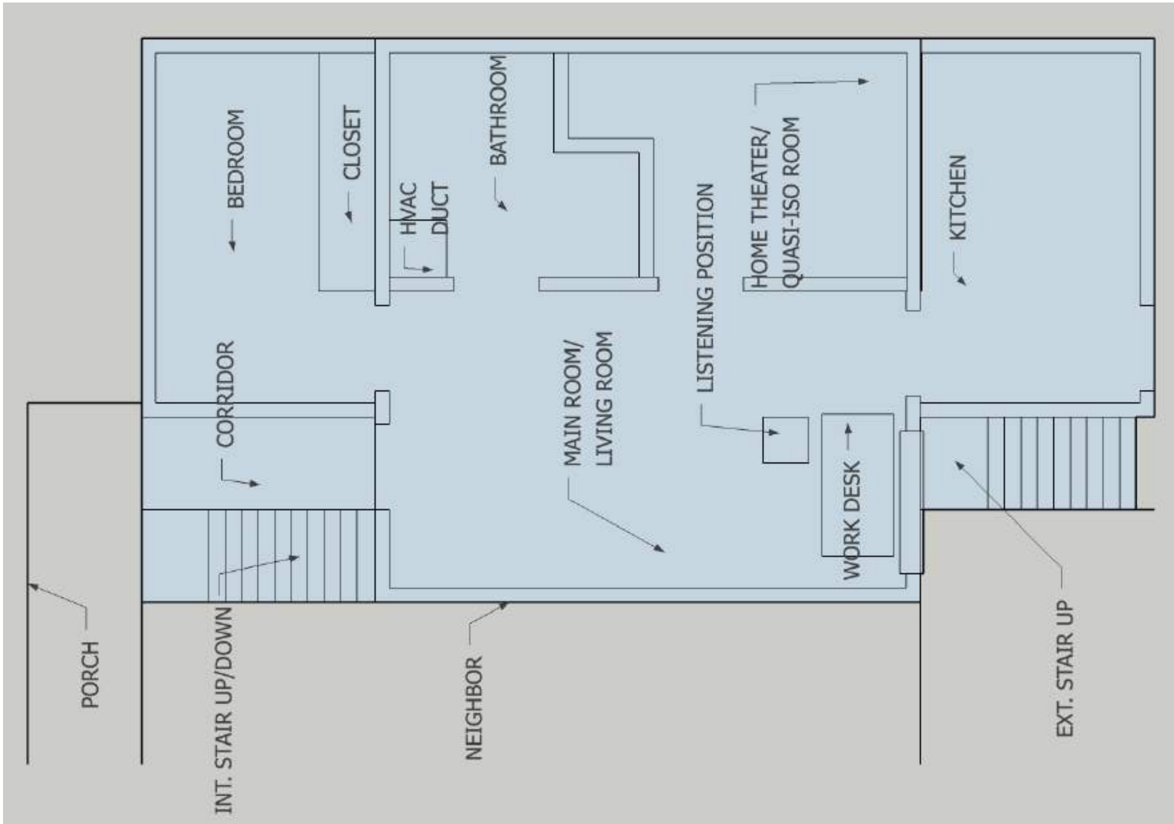
Most of my isolation problems can be solved socially: I have a dog with a mind of her own, but besides that, my wife and I can plan working sessions and other domestic activity around each other in my own space, and transfer is low enough from the other spaces to make recording intrusions acceptably rare, even on quieter takes. Transfer out to the other apartments is presumably similarly low, and I've produced sound at the levels needed for my work multiple times without any complaints, even on playing loud pink noise and sine sweeps for measurement. In either case, I limit my loudest activities to daytime hours.

Exterior sound transfer is virtually a non-issue as I live in a well-insulated house in a quiet neighborhood, away from any flightpaths or other large exterior noise sources. Occasionally the sounds of a car pulling into our driveway or people walking up the exterior steps leak in our window, but these times are acceptably rare and happily solved by a new take. Thus, my primary sound isolation concerns are domestic noise transfer between rooms within my apartment due to concurrent uses such as appliance use, cooking, cleaning, and living.

Briefly on HVAC concerns: my apartment seldom needs A/C, which can be provided by a window unit A/C at my convenience. It is heated with a natural gas, forced-air furnace. The furnace is present enough to preclude quiet takes when active, but owing to the apartment's very effective insulation, it is on in short bursts in the winter with long silences in between. One solution I've found when I need a longer time of silence is to turn up the thermostat for a time to heat the room to a comfortably toasty level and then turn the thermostat back down. Entropy continues and the room cools down, but the furnace sits longer before needing to kick back on. I don't have access to the furnace to adjust fan speeds or to the ducts to apply any treatment internally, so the above social solutions are the extent of this project's approach to the HVAC.

Existing Configuration

The room was already configured to serve the dual purposes of studio and living room. The couch was along the long wall, which it must be, as it won't fit any other way. The couch faced a TV on a side table along the opposite wall between the two doors on that wall. My studio desk was placed by the kitchen door, in front of the window, with speakers firing down the length of the room. The listening position, by necessity is somewhat off the room's center axis, and quite close to the side wall, with speakers very close to each other,



Pictured: Site overview, NTS, including existing listening position

<u>Design Criteria:</u>

- Design will focus on the main room and will consider interior room acoustics, noise transfer within the apartment, ergonomics and aesthetics.
- Design will center around the multi-purpose nature of the room, as a living room, critical listening area, and recording space.
- Design may move equipment and furniture as is practical, but must include most of the existing furniture pieces in the room, or make provision to move pieces to another room.
- Acoustic treatments and equipment should be modular, portable, and useful in other locations not specified, to the maximum extent possible.
- Major/destructive/permanent architectural changes will not be considered.
- Where site-specific treatments must be made (such as LF absorption), treatments which can be tuned or modified in the future are preferred.
- HVAC will be addressed minimally if possible. Otherwise, social solutions will prevail.
- Design will not consider exterior noise transfer, essentially a non-issue in this space, and where issues arise, social solutions are acceptable.
- Design will not include the home theater at this phase, though it should be treated for internal room acoustics at a later time and may benefit from the use of modular treatments developed in this phase.
- Design will assume use of existing equipment, but not be equipment-centered.

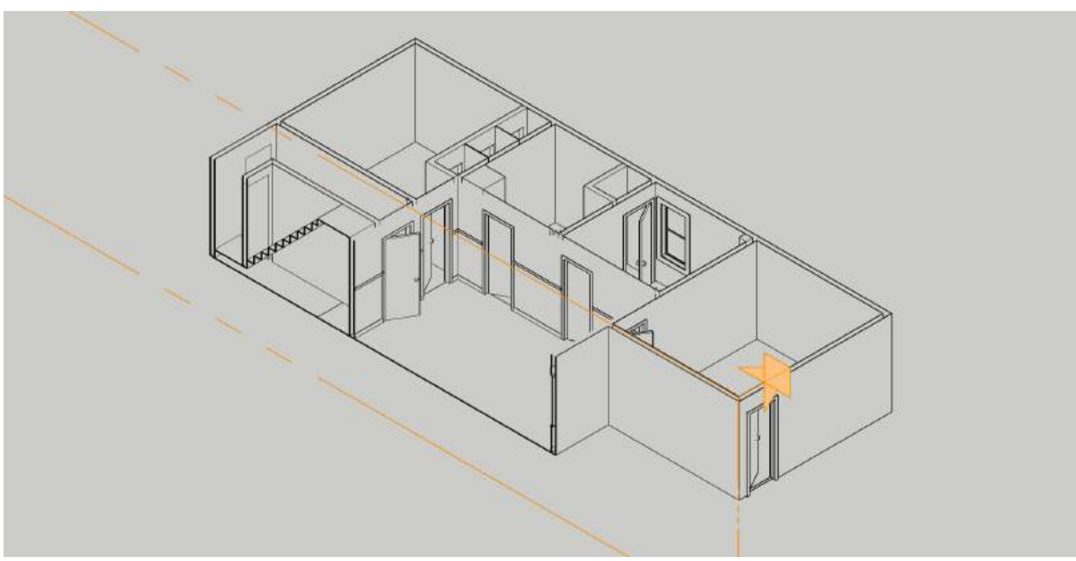
Section 2: Layout investigation

Existing Building Architecture:

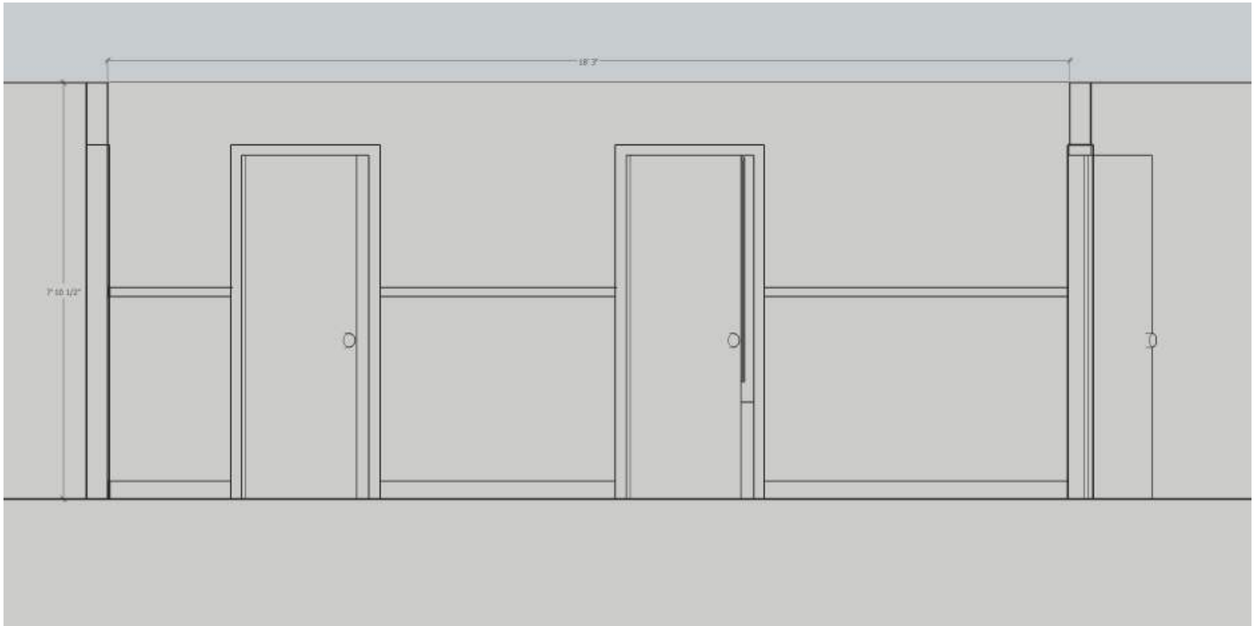
The living room studio is largest of five rooms in my apartment, and acts as a central pass-thru between all of them, as well as to the front entry corridor. My wife, our guests, and I usually enter through the kitchen at the rear instead. There is also a large south-facing exterior window at the kitchen end of the room, which provides a good amount of natural light. The kitchen door and window are the primary entry paths for noise. The ceiling is a drop-tile ceiling with 1" rigid insulation tiles, with a 3" air gap above to the hard gypsum ceiling.

The room dimensions are 18'3" L x 10'4" W x 7'10.5" H

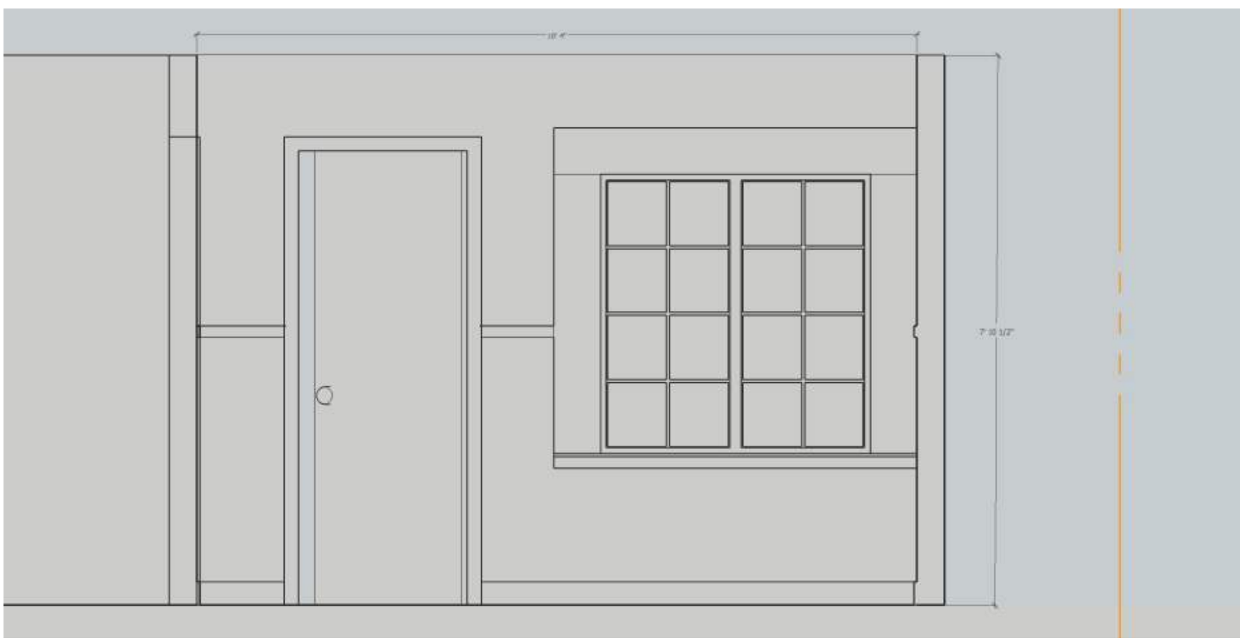
Render of existing apartment architecture, note the preponderance of doors in the main room.



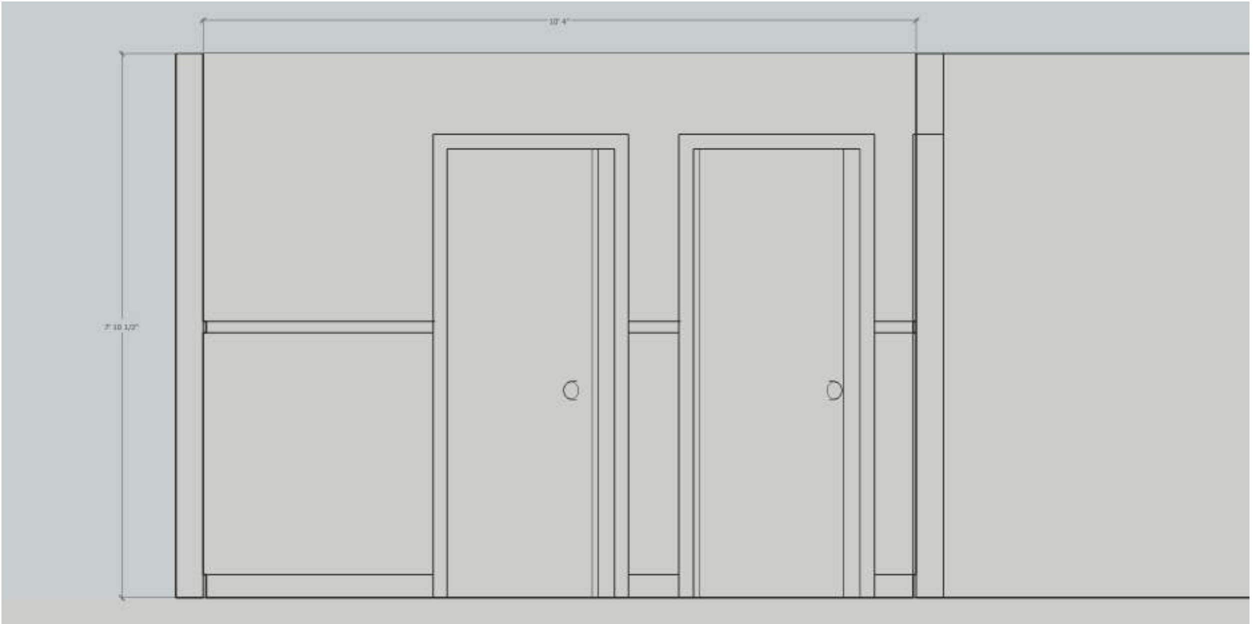
Iso section, the entry door on the north (left) is the only door that swings into the room.



Interior: Main room east wall, doors to bathroom (left) and home theatre (right), kitchen door is shown ajar on the far right



Interior: Main room south wall, door to kitchen and exterior window



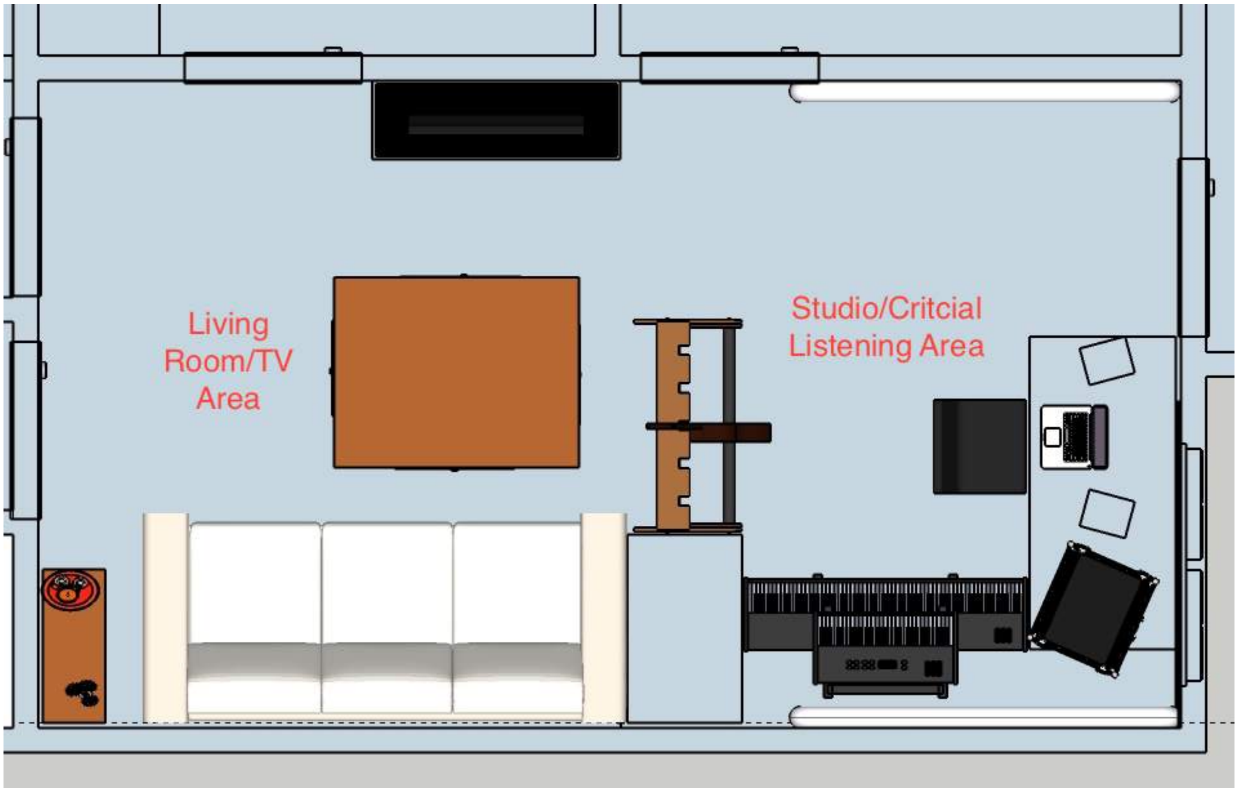
Interior: Main room north wall, doors to entry corridor (left) and bedroom (right)

Furniture:

The apartment is furnished with a number of pieces that can be rearranged but cannot be removed, including this large pull-out sofa, large coffee table, wooden chest and bookshelf, and two twin mattresses.

Initial layout:

The existing configuration of the living room studio separated the two functions of the room, creating a studio space in one end of the room and a living room space in the rest of the room:



Plan view, initial room layout, separated functional areas.

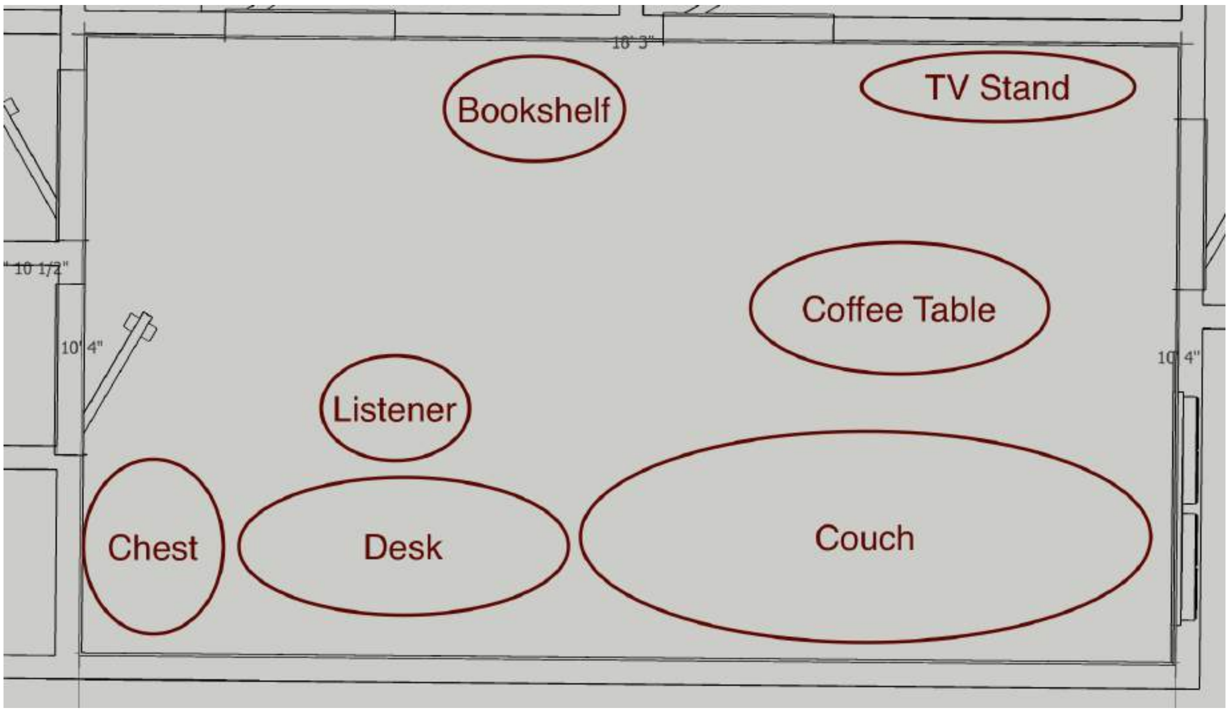
Render, POV from kitchen door, initial room layout

Render, POV from bedroom door, initial room layout

Besides a total lack of symmetry and flow for either part of the room architecturally, this arrangement caused a number of problems purely from an acoustical design perspective. The listening position is off center side-to-side and very close to the right side wall, with the side wall reflections causing destructive comb-filtering, compounding the inevitable front wall speaker boundary interference. The arrangement also made for a cramped tracking area, leading to space usage and storage spilling across the imaginary line into the living area. Finally, the arrangement also placed the listening position in close proximity to the two worst noise problems of the room, the kitchen door and the window.

Layout Iteration

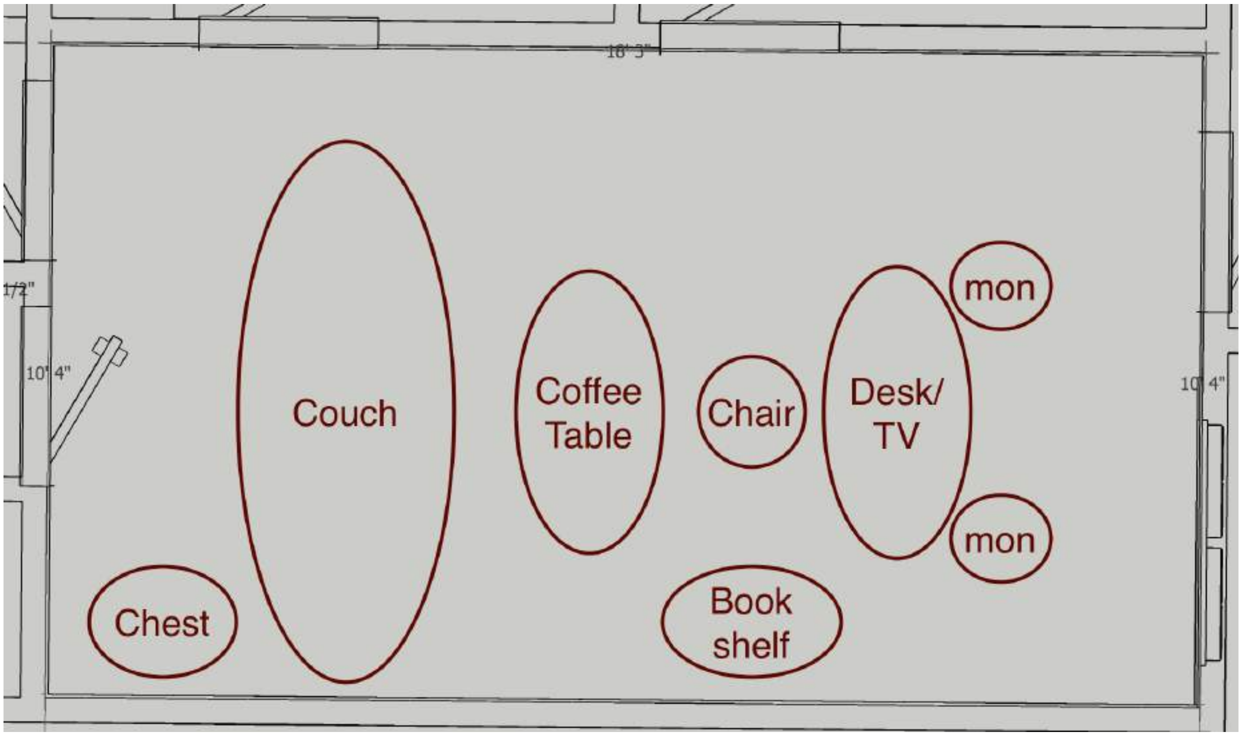
Given the numerous design constraints, there were not many other design options that maintained the separation of functions. One concept design, traded the ends of the room, with the couch slid over by the south window facing the east wall, and the desk moved to the north side on the west wall:



Redesign concept 1

While this concept moved the position farther from the problem noises of the kitchen and window, it had almost the same issue with off-center position and proximity to a side wall. It also put the speakers with their backs to a wall shared with a neighbor, potentially causing coupling and transfer to the next apartment, risking neighbor relations. It would also likely create a tripping hazard with the coffee table right in front of the kitchen door. Other attempts to maintain separate areas for separate activities failed for similar reasons.

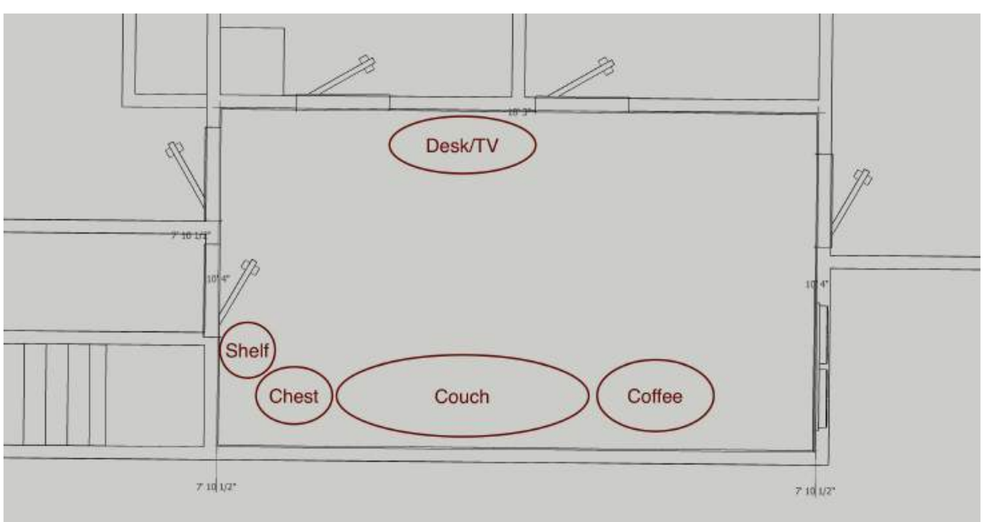
The topic arose of improving the situation by consolidating the functions of the shared space. The intuitive solution for this was to use the work desk as a TV stand. This would make new configurations possible, allow for the removal of the TV stand, and for me to sell off a spare display by using the TV as a computer display. One proposal kept the desk facing north, and placed the couch across the short axis of the room facing south toward the desk:



Redesign concept 2

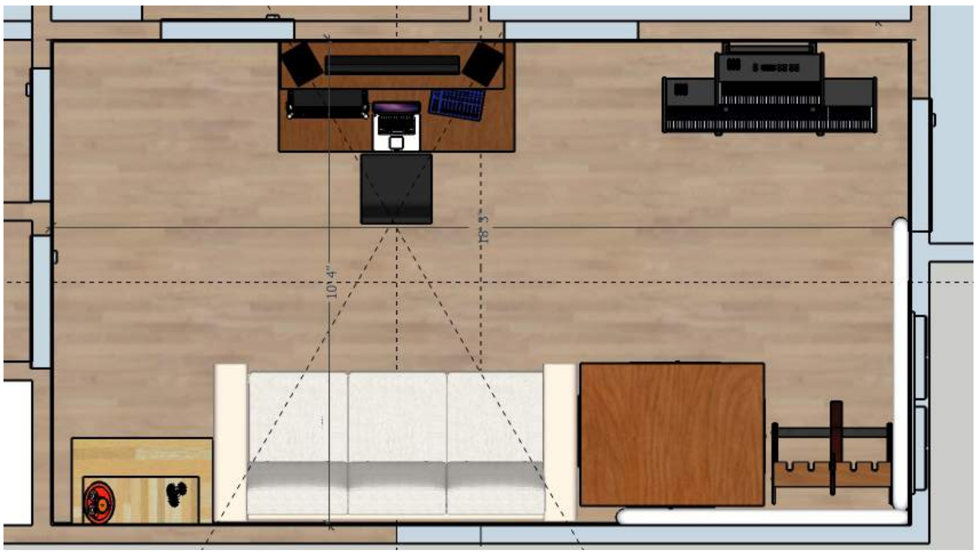
This concept improved distance from the side walls relative to the initial setup, and also moved the monitors away from the wall and off the desk to improve response. However, it also crowded a lot of furniture into the center of the room, and concerns about walking clearance around the left monitor and around the couch eventually ruled out this design, and any others with the large couch anywhere but against the long wall.

Finally, a design arose with the desk centered on the short wall between the bathroom and home theater doors where the TV had been in the initial setup, and the couch against the west wall, centered on the desk:



Redesign concept 3, the final concept chosen for development

This moved the listening position to close to the center of the long axis, far from each side wall, while creating a symmetrical area with the couch able to be properly centered on the TV. This arrangement also created a larger empty floor space, making for the best pass thru traffic path yet and plenty of room to move around while tracking or performing other activities. Additionally, the listening position is moved farther from the kitchen and window, and the speakers back up to an internal wall, where noise transfer makes less of an impact on neighbors. A fringe benefit is the good potential for sightlines from the listening position through the doors into the bedroom and home theater room, each of which could serve as an ad hoc iso space in a moment of need. This design was chosen for further development:



Proposed layout update, note improved traffic flow and symmetry.

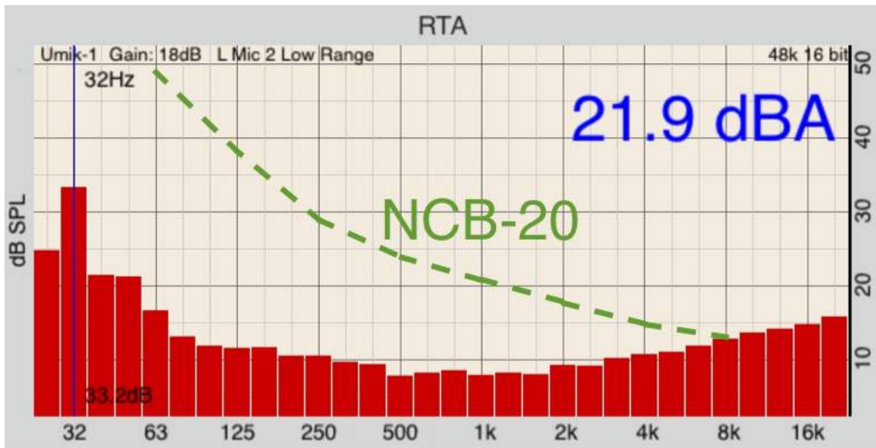
Render, POV from entry door, proposed layout update

Render, POV from kitchen door, proposed layout update

Render, POV from couch, proposed layout update

Section 3: Isolation Acoustics Analysis and Treatment

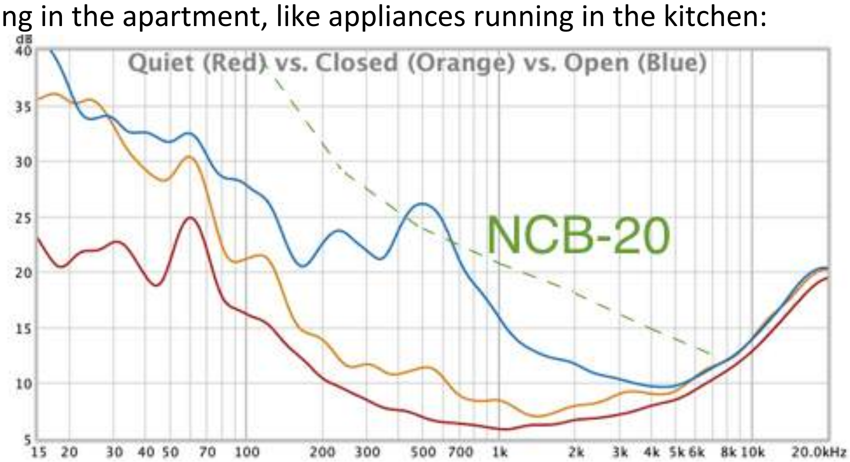
While major isolation is out of the scope of this project, noise measurements were made to evaluate current conditions and for future reference, in quiet conditions and with problem noise sources active:



Calibrated mic RTA of the room in a quiet state, via AudioTools RTA module.

Under quiet conditions the room easily meets an NCB-20 standard for a recording studio/control room, more than quiet enough for my purposes. This state can usually be achieved with careful planning of sessions, and management of the HVAC system, and is preferred for mic tracking.

I'm still comfortable doing listening tasks under other conditions, such as with more activity happening in the apartment, like appliances running in the kitchen:



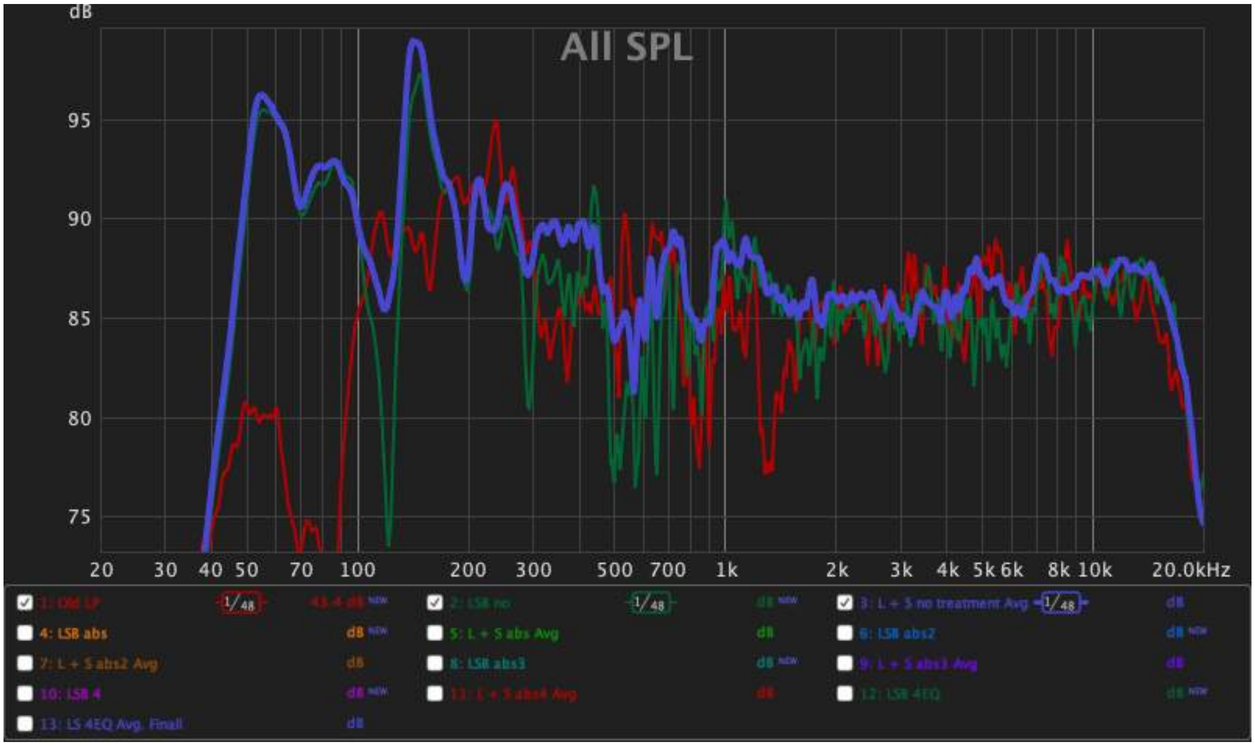
Noise level comparison, quiet vs. with appliances running in kitchen (doors open vs. closed)

Even with the appliances running, noise levels are good enough for me. I will be applying an adhesive door seal kit to my kitchen and other door frames to gain a few dB of isolation during activities in other rooms. This is low-hanging fruit for isolation, and will be a cost-effective way to gain a few dB of useful isolation:

Adhesive door seal kit, for sealing gaps around doors. From Audimute: < https://www.audimute.com/acoustic-door-seal-kit?___store%5B_data%5D%5Bstore_id%5D=4&___store%5B_data%5D%5Bcode%5D=audimute_en&___store%5B_data%5D%5Bwebsite_id%5D=4&___store%5B_data%5D%5Bgroup_id%5D=4&___store%5B_data%5D%5Bname%5D=audimuteacousticpanels.com+-+english&___store%5B_data%5D%5Bsort_order%5D=0&___store%5B_data%5D%5Bis_active%5D=1&gclid=EAIaIQobChMIz4-U9ZHL6AIVGHiGCh1FUA23EAYYAiABEgK1L_D_BwE >

Section 4: Internal Acoustic Analysis

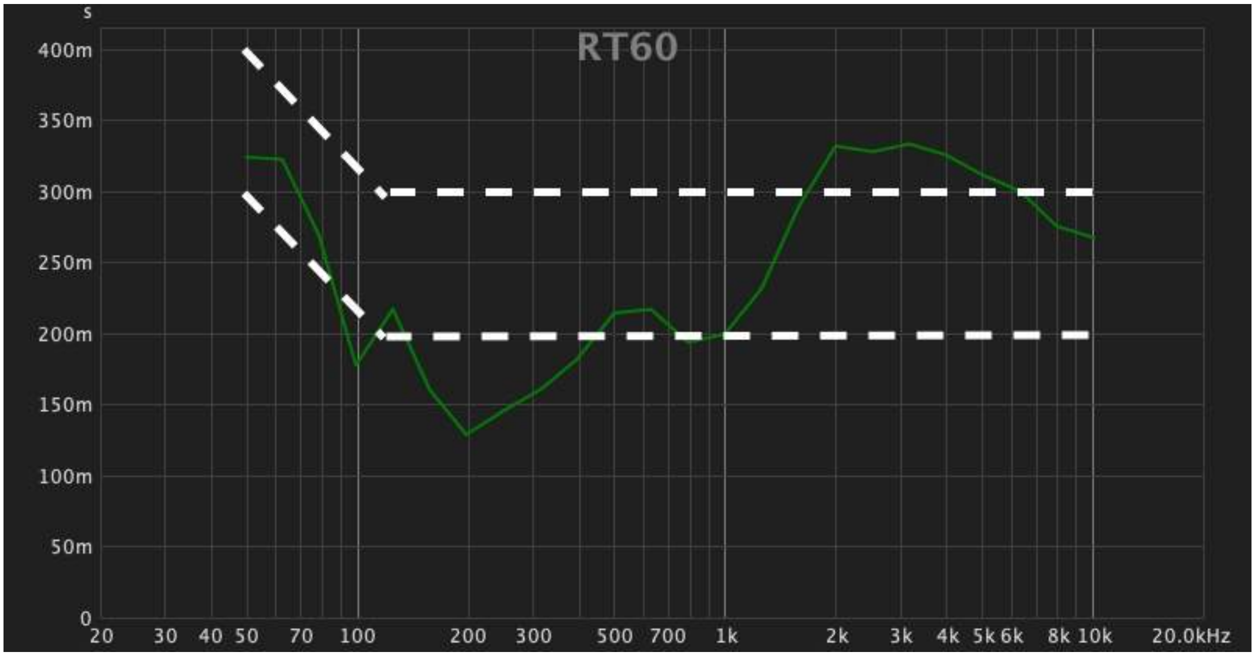
Frequency Response:



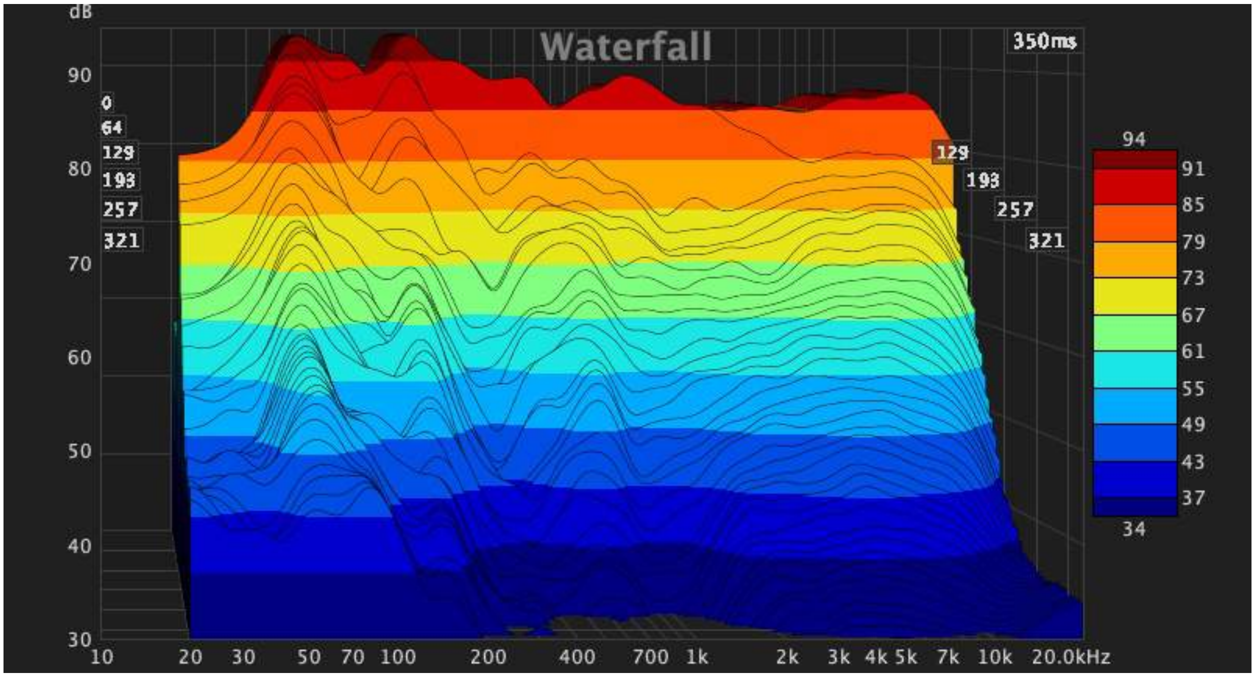
New listening position average (blue) vs. new listening position single sweep (green) vs. old listening position single sweep (red)

The new listening position shows significant improvement in frequency response compared to the old position. Comb filter issues at the old position were more drastic and serious cancellations appeared higher in the spectrum, owing to the closer walls. The new position still shows significant response dips, likely also due to comb filtering in the mid-range and a combination of modal issues and speaker-boundary interference in the low range.

Room reverberations and decay time:



RT60, estimated via REW's Topt algorithm, 1/3 octave bands, against target range



Waterfall graph, full range, 1/3 octave smoothing applied

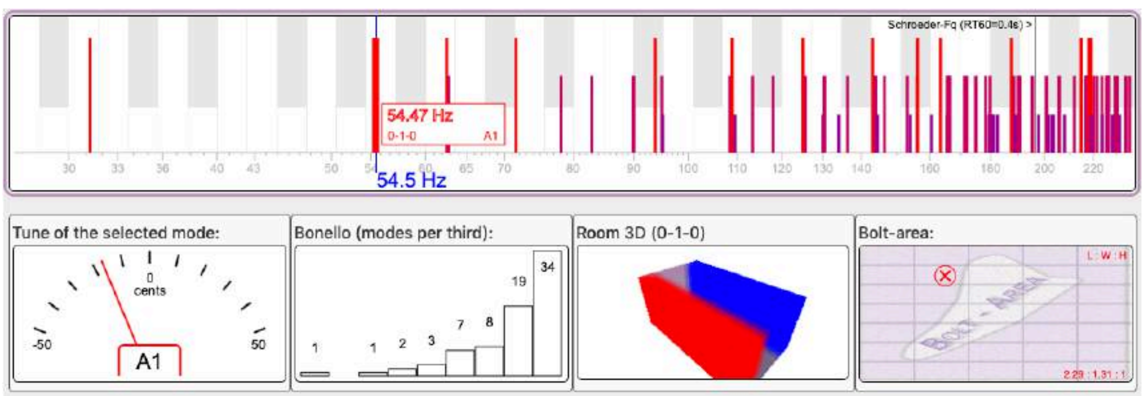
Decay time in the room is in a good range overall, based on a listening room standard of .2-.3 seconds. The RT60 graph reveals the room's slight "bright" tendency, showing a room response dip in the middle frequencies, and decay times about twice as long in the lows below 100Hz and high end above 1,000 Hz. The waterfall graph provides more detail, confirming the broad rise in decay time in the high end and highlighting the very short decay of frequencies between 200 and 300 Hz.

The rapid decay between 200-300 Hz, is likely due to speaker boundary interference response from the speaker to the back wall, at the listening position, and as such, is difficult to treat without an infinite baffle. This could also possibly be the result of modal distribution, an unidentified source of absorption in or adjacent to the room, or furniture bounce from the speaker to the desk, and will be revisited in low-frequency analysis.

Based on these room decay parameters, designs should include some targeted LF absorption targeted below 200Hz and mid and HF absorption targeted above 1K to support an even room response overall. Absorption in the low-mid range will be revisited in low frequency analysis.

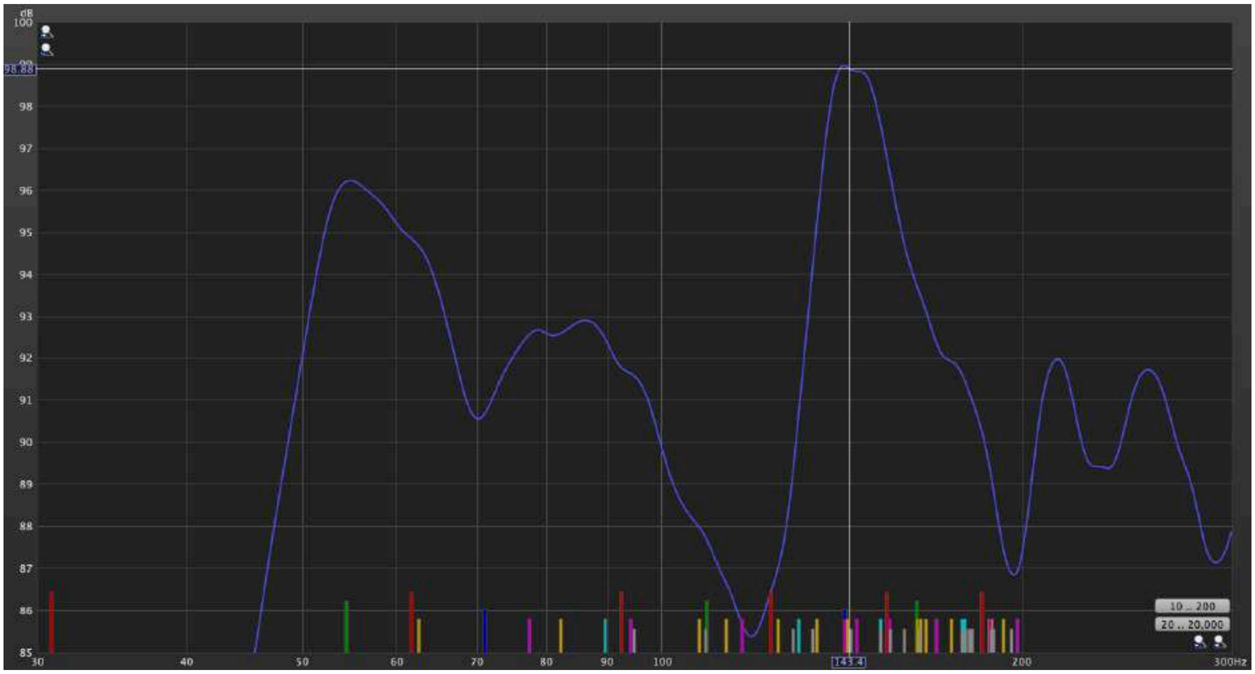
Low frequency analysis

The dimensions of the room are 18’3” L x 10’4 W x 7’10.5 H. I used amcoustics.com’s amroc room mode calculator as a tool to help analyze the room’s low frequency response:



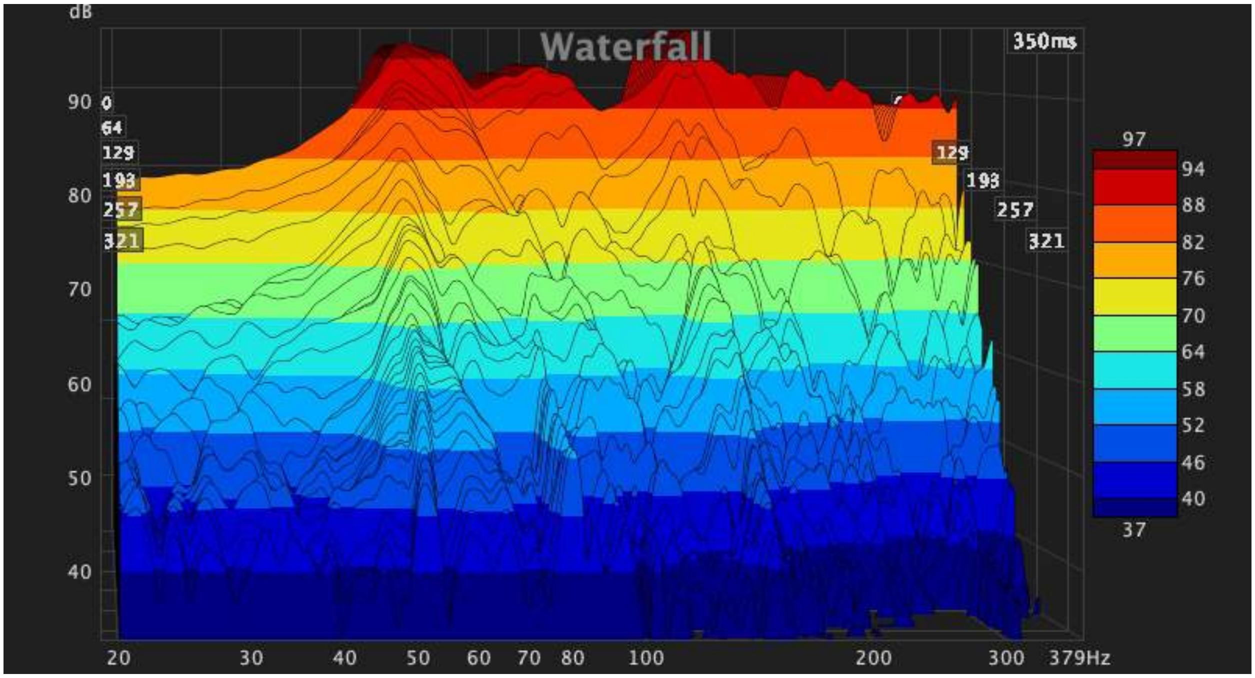
Quick indicators like the Bolt area and Bonello’s modes-per-third octave rule indicate that the room’s dimensions are less than ideal, but not far off. We can expect some uneven modal distribution issues, but the room is useable. If it were within the scope of the project, I would put up a wall to create an iso space or storage and shorten the room by 4 feet to put it within the Bolt area and improve modal distribution overall.

While my sound system doesn't reach much below 50 Hz, measurements still demonstrate how the room modes play out in real life:



Averaged sine sweep measurements show peaks and valleys of spanning over 20 dB in the bass range, many of which may be explained directly by modal activity. First is a peak at 54.5 Hz, corresponding to the 0-1-0 room mode, which the speakers are placed in the apex of, against the wall. A dip in the response at 70 Hz, corresponds to the 0-0-1 mode, which the speakers sit near the null of, in the middle of the height of the wall. A dip at 118 corresponds to the 3-0-1 and the 1-2-0 oblique modes and the 4-0-0 axial mode, all of which the speakers sit near the nulls of. A huge peak at 143 corresponds to the 0-0-2 mode, which the speakers are in a peak of, again in the middle of the height of the wall.

Even at and above 200Hz, the approximate Schroeder frequency, modal response can continue to explain problems in the low mid-range. A dip centered at 197 may correspond with an area of less modal support between dense modal distribution areas, and a peak centered at 217 corresponds with a rare near coincidence of multiple axial modes (0-0-3, 0-4-0, 7-0-0) and several oblique and tangential modes. Above this area, modes converge and become evenly distributed through the room.



A waterfall analysis also supports the previous frequency response conclusions, especially below 200 Hz. Those frequencies supported by the apex of a mode ring longer, especially the 54 Hz and 143 Hz modes, and those cancelled by the null of a mode die more quickly, notably the 70 Hz null.

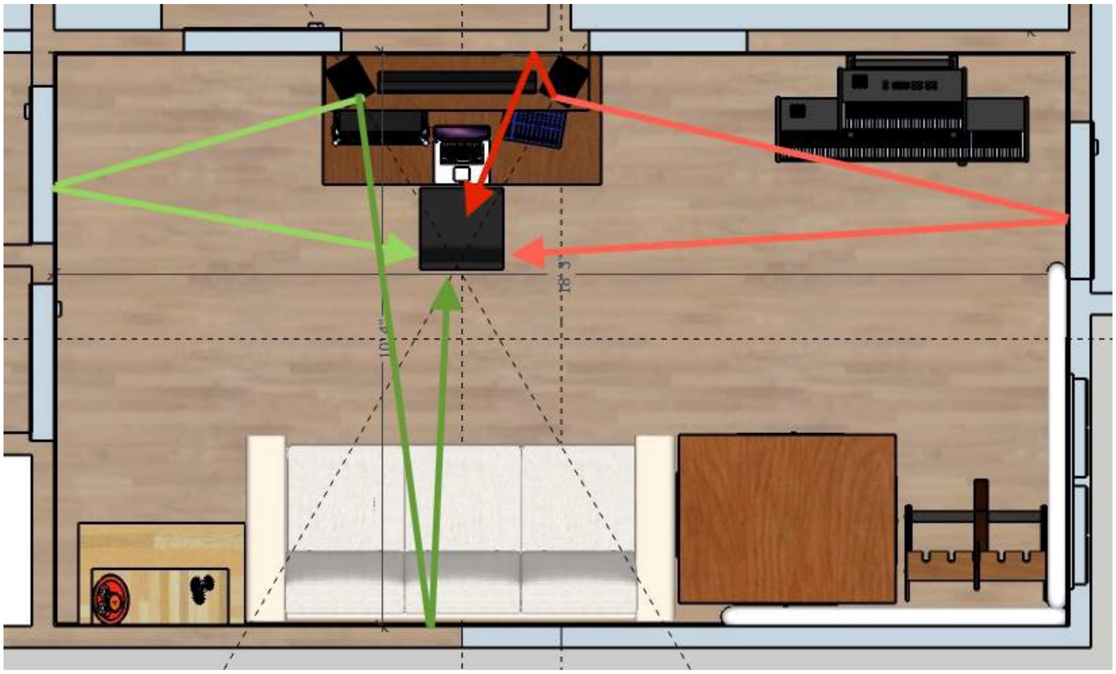
This low frequency analysis recommends two particular changes: moving the speakers, and applying targeted low frequency absorption.

Moving the speakers can help reduce the effect of room modes on their output, particularly moving them in the vertical to get them off the center of the height of the room, to get them out of a room null, and if possible, moving them forward to get them away from the front wall, which may be impractical due to the available space.

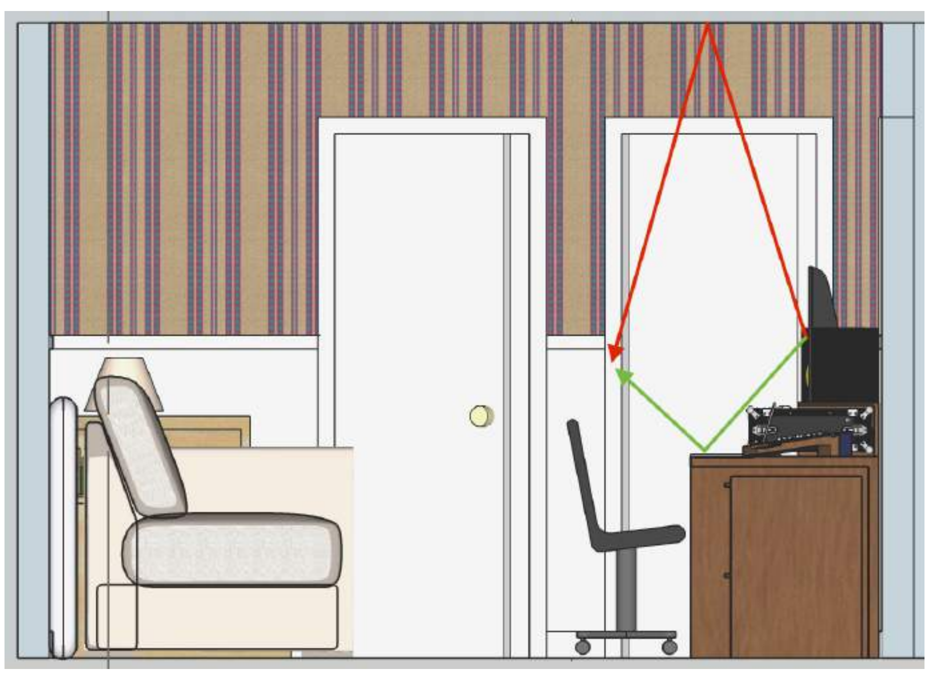
Low frequency absorption should be a major component in improving the response of any sound-critical room. In this case, targeted absorption treatments tuned to about 55Hz and 145 Hz will be most beneficial. In keeping with my goal of modularity and portability, I'll seek to design treatments that are modular and portable, and in this case treatments that are able to be tuned and retuned for future spaces.

High frequency, reflections and ray-trace analysis

In the previous configuration, one of the major acoustic issues was comb-filtering caused by reflections from all the nearby surfaces. The move of the listening position to the center of the room, farther from side walls, improves the first reflections issue, but it can still be improved:



Overview, HF ray trace



Side view, HF ray trace

The side wall issue has not been eliminated, but has been mitigated and will be easier to treat. More important now are the bounces off the ceiling, desk, and rear wall. While I can't use speaker stands because I can't take the space to pull the desk forward into the room more, I can help the situation by flipping my monitors tweeter down, lowering them to the plane of my ears, and improving the furniture bounce:

Side view, ray trace with speakers inverted (solid lines), note improvement vs upright (dashed).

One major remaining issue that particularly affects the approach to reflection treatment, is the issue of symmetry. Being off center, the listener experiences reflections from each side at different times, negatively impacting stereo imaging and compounding any existing comb-filter issues.

Final acoustic designs should and will address symmetry, and will include some HF absorption above 1K, and a combination of reflective elements around the desk to direct reflections away from the primary listening position toward the rear wall, where mounted diffusion will scatter reflections evenly through the room.

Section 5: Internal Acoustics Design

Design Criteria and Goals:

The design process was begun with several criteria in place:

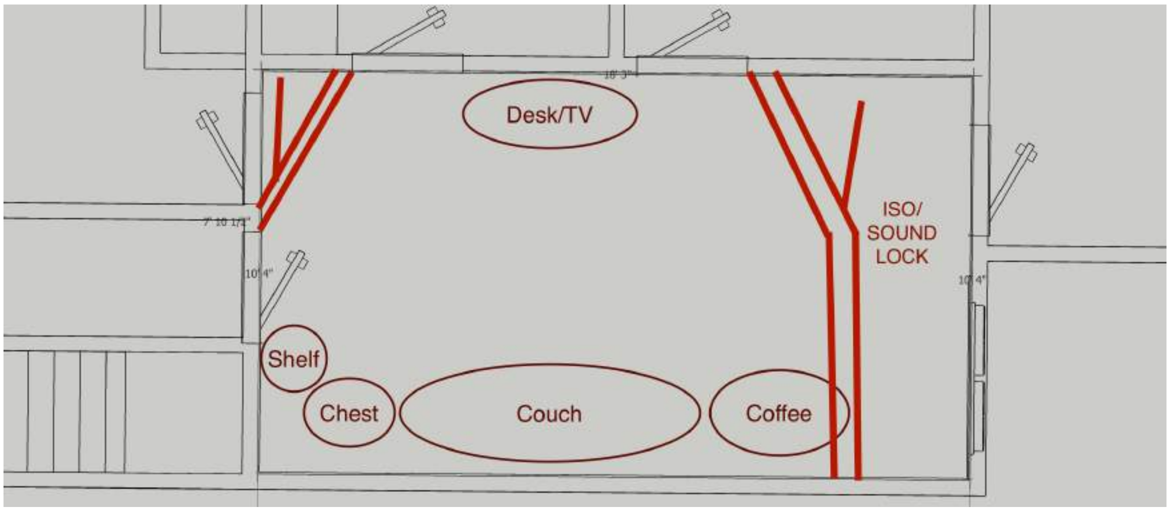
- Design will focus on the main room and will consider interior room acoustics, noise transfer within the apartment, ergonomics and aesthetics.
- Design will center around the multi-purpose nature of the room, as a living room, critical listening area, and recording space.
- Design may move equipment and furniture as is practical, but must include most of the existing furniture pieces in the room, or make provision to move pieces to another room.
- Acoustic treatments and equipment should be modular, portable, and useful in other locations not specified, to the maximum extent possible.
- Major/destructive/permanent architectural changes will not be considered.
- Where site-specific treatments must be made (such as LF absorption), treatments which can be tuned or modified in the future are preferred.
- HVAC will be addressed minimally if possible. Otherwise, social solutions will prevail.
- Design will not consider exterior noise transfer, essentially a non-issue in this space, and where issues arise, social solutions are acceptable.
- Design will not include the home theater at this phase, though it should be treated for internal room acoustics at a later time and may benefit from the use of modular treatments developed in this phase.
- Design will assume use of existing equipment, but not be equipment-centered.

Additionally, acoustical analysis identified several goals for the acoustic design:

- Flatten room frequency response by addressing issues arising from reflections and modal response of the room.
- Even out decay time across the spectrum by providing broadband absorption above 1K Hz and targeted LF absorption below 200 Hz, while avoiding further absorption in the low midrange, and without reducing the overall reverb time too much.
- Low frequency absorption should be low-Q (relatively broadband), but center on modal problem frequencies around 55 Hz and 145 Hz.
- Speaker placement should be adjusted move speakers out of modal problem areas, and to optimize inevitable speaker-boundary interference response.
- Speaker placement should optimize for furniture-bounce to reduce comb-filtering.
- Design should minimize reflections at the listening position, by making use of a combination of absorptive and reflective elements around the listening position.
- Design should include diffusion mounted on the rear wall to further direct reflections away from the listening position.

Portable reflection-free zone concept

In design iterations, I considered briefly the solution I would take if serious construction like walls were an option. It involved moving the bedroom door on the left side and creating new walls on each side, including the creation of a storage or iso space on the right side:



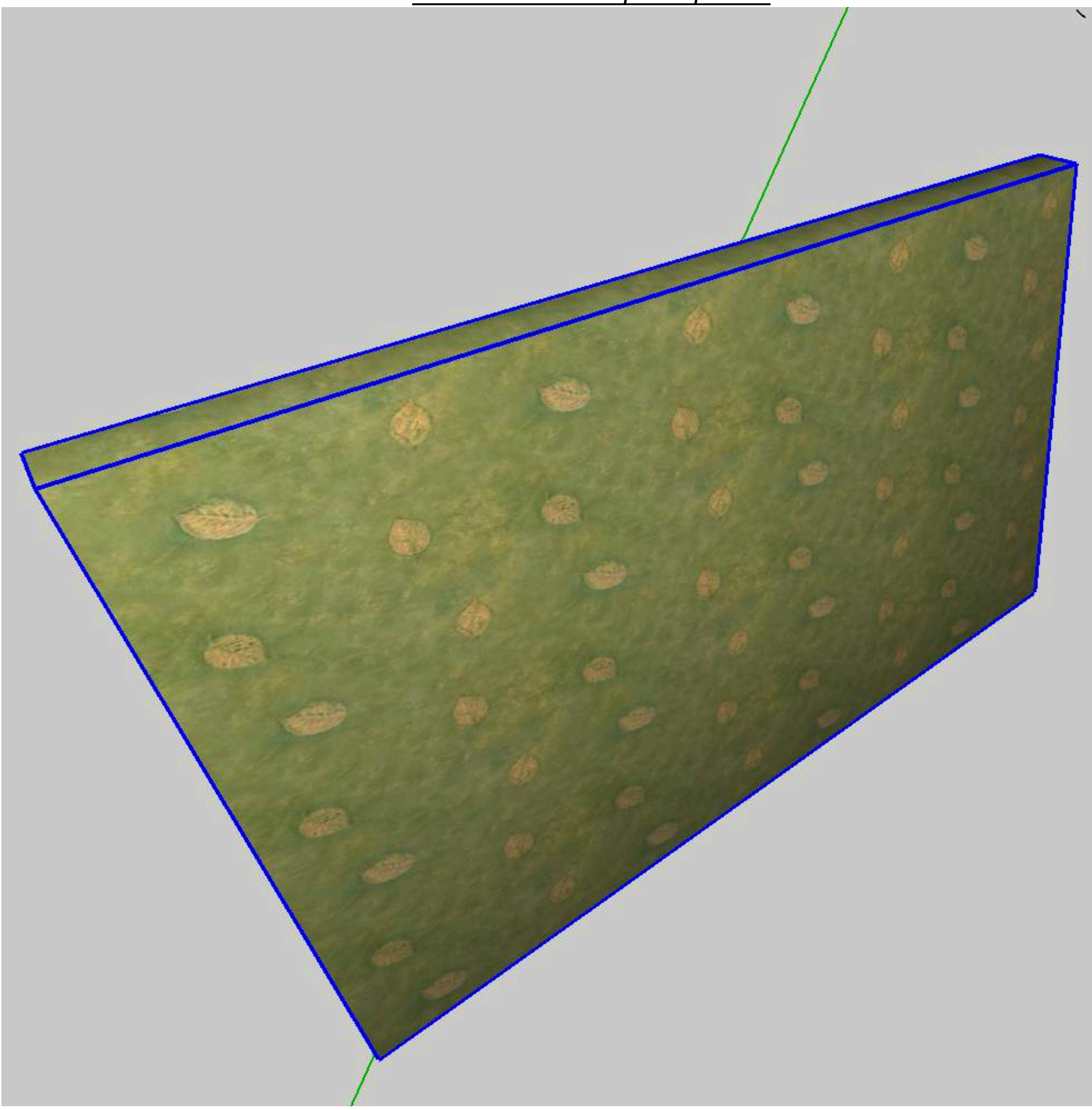
The concept addressed two of the room's biggest problems: symmetry about the listening position, and the modal proportions of the room. Of course, the concept was well outside the scope of this project, but it was a useful exercise in that it led to another iteration that was actually possible – creating a reflection-free zone with portable modules.

The beginning of my modular reflection-free zone plan, built around simple panels angled on each side of the listening position.

Acoustic treatment modules

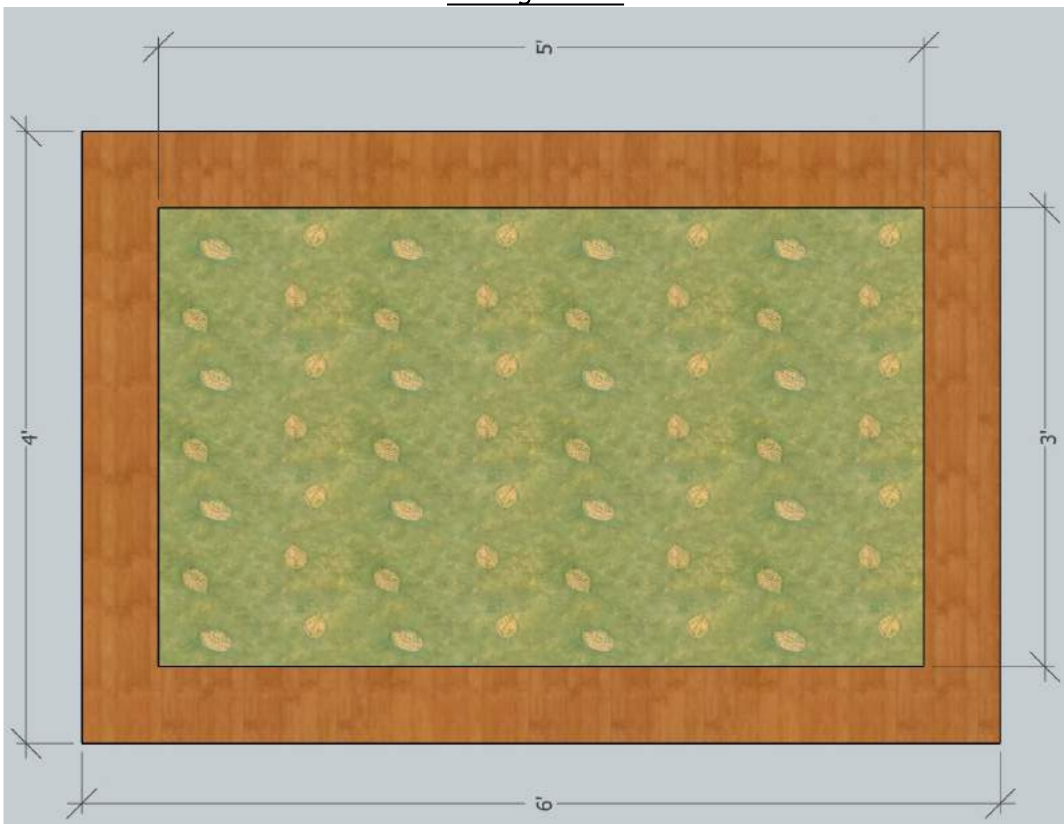
I've known since the beginning of this process that any design approaches I took would have to be portable and modular, rather than custom-built into my current space. However, I've been pleasantly surprised through this design process by how useful a tool this first use-case has been for helping me find or design the most functional and variable modules possible:

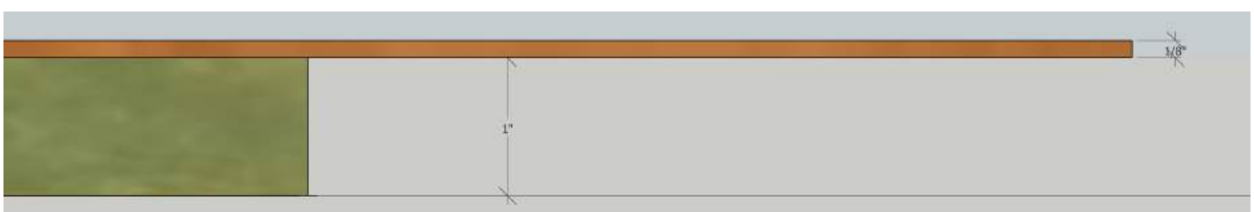
Broadband absorption panel:



I've designed and built these in a number of sizes, including 2" and 1" thick versions and panel sizes from 2'x3' to 4'x6'. Only a few are currently in my apartment and the rest are quarantined at my office. These consist of old OC103 fiberglass insulation (found for free!) wrapped in an inner cotton layer and an outer decorative fabric layer, applied in such a way that the panels can easily be re-skinned. Mounting options will include French cleat mounts and picture-frame hooks. Spacers may be used to target lower frequencies.

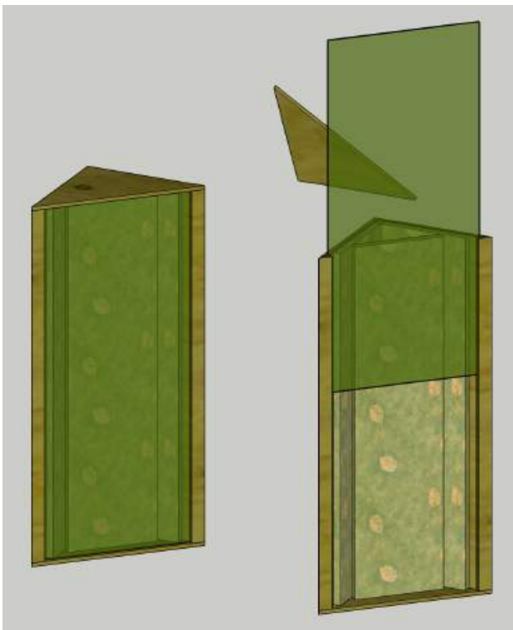
Ceiling Cloud:

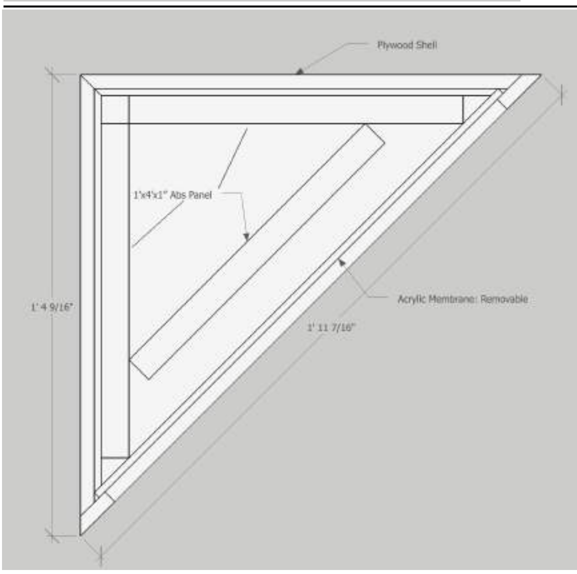


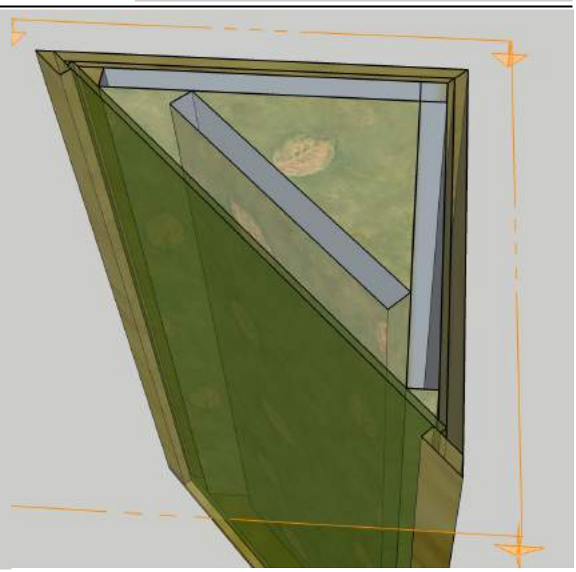


This ceiling cloud module will be built with a 1" thick 3'x5' broadband panel mounted to a 4'x6' 1/8" plywood sheet. Hanging hardware will consist of eyebolts at four corners, bolted through the plywood sheet and suspended, in this case by wire run through the drop ceiling grid. It could also be screwed directly to a ceiling with or without spacers. Eyebolts are simple to remove and reverse, allowing the cloud to be hung absorption up or absorption down easily. The panel is lightweight and may upon build be found to require bracing to make rigid. If needed, this will consist of a 1x2 X-brace across the reflective side, and if more rigidity is still needed, a 1x2 perimeter frame will be added.

Modular Corner Membranic Absorber:

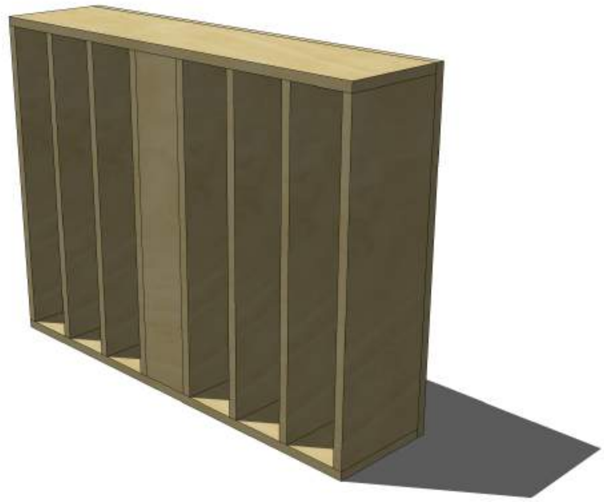


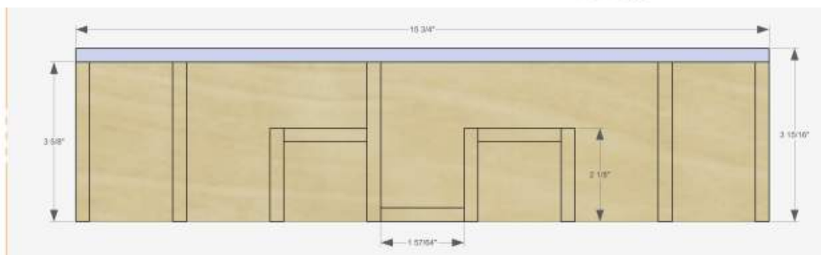




This is an original membrane absorber, designed to be compact, modular, stackable, and lightweight. It fits into any corner at 1'4 9/16" across each back side and 1'11 7/16" across the front, but provides over 6 square feet of membrane surface per unit. The interior makes use of the previous absorber panel design to soften the "Q" of the unit. Additionally, the top is easily removable, so the membrane can slide out and be replaced at any time with another membrane of the same size and between 1/8" and 1/4" thick, with a perfect seal. The interior panels may also be removed to narrow the tuning of the absorber. A 1/4" acrylic membrane targets a design frequency of 50Hz; 1/8" acrylic, 72 Hz; 1/8" Plywood, 99 Hz. Transparent acrylic is particularly attractive for its beautiful design potential!

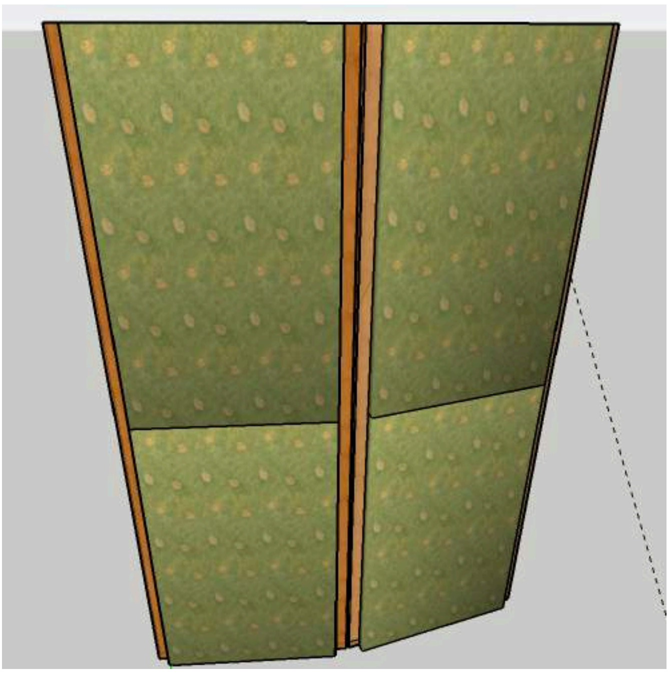
Diffusion Module

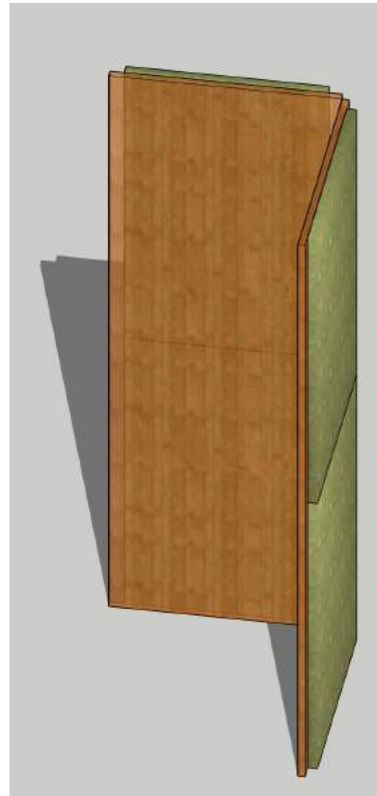




This N=7 QRD "inspired" diffuser module design is borrowed from Gernot Ebenlechner, an active participant in the Gearslutz.com online forum for home studio owners and other industry practitioners. The concept (supported by academic literature) is a "folded-well" diffuser. Space behind 1 and 0 depth wells is added to other wells to allow five depth levels in the space of two. This makes for a compact, efficient module. Designed to be arrayed in pairs with the period facing the opposite way. More info in the forum at < https://www.gearslutz.com/board/bass-traps-acoustic-panels-foam-etc/369164-diy-diffusors-max-12.html?fbclid=IwAR3NTCPA3nwjN3LSCDrU4FEvAwohMPqzX-YuzWo2tSLFqzWz9xHcF4-38IU#post6061048 >

Modular dual-sided gobo





Consisting mainly of sheet of ½"Plywood (cut in half), four of my existing 2'x3'x1" absorber panel modules, and a set of loose-pin hinges, each of these folding gobos is simple as can be. They're designed to stand on edge folded or by being attached to a structure. They're joined by loose-pin hinges, so they are easy to separate, and additional hinges on each edge make it possible to join multiple sets of panels together. Each panel has a reflective plywood (optionally slatted) side, and a broadband HF absorber side. They can fold flat to store against the wall, decorative absorber panels facing out, and they can open to 270 degrees, allowing for many different configurations.

Planned module usage

These modules, while designed to be completely transferable to another space, each will have a specific set of uses in the current space.

The broadband absorber panels will be mounted on each door in the room at head height to knock down early reflections during tracking and production, and leisure listening, particularly at the first reflection points on the bedroom and kitchen door. Additionally, two absorber panels supplement the low-mid absorption in the room design by straddling the rear corners, atop the membrane absorber modules. Spare absorber panels will be useful for variable acoustics during tracking.

The ceiling cloud will be hung above the desk, absorptive side down, and angled to deflect early reflections from the ceiling to the diffuse rear of the room, alleviating flutter echo and comb filtering for the listener. In the future, an additional cloud module may be made to serve a similar purpose over the tracking area.

There will be two of the corner membrane absorber modules, each outfitted with a 1/4" acrylic membrane to be tuned to 50 Hz. They will reside in the trihedral corners on the floor at the window end of the room. In an ideal world, I would include more with different tunings in this design, but the room is out of room.

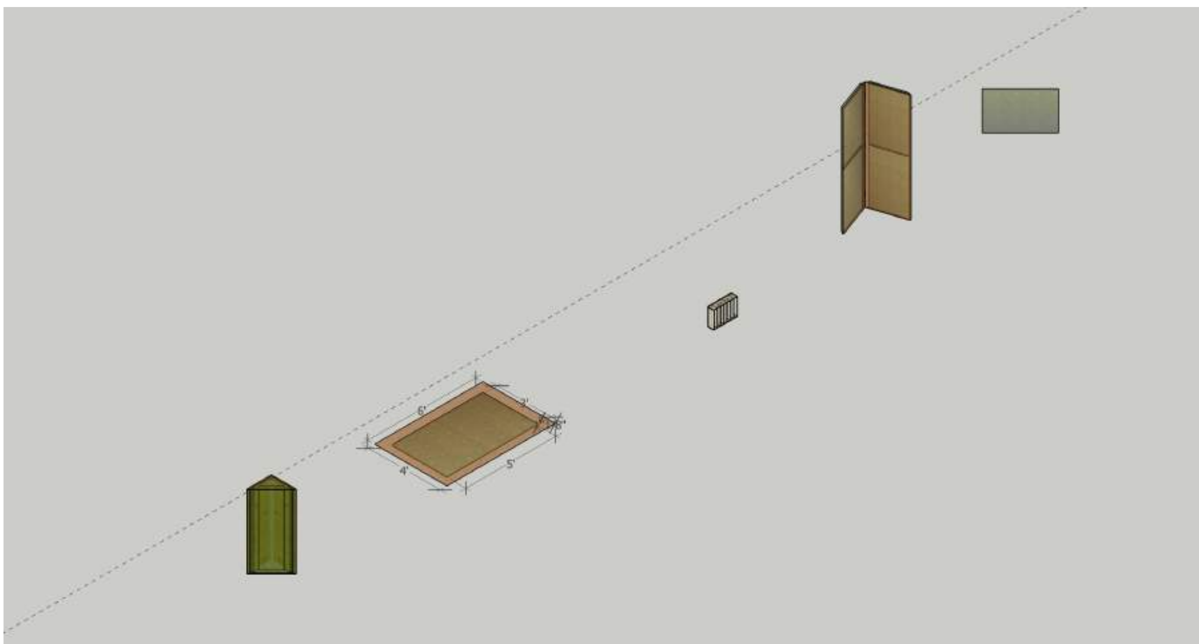
The design includes eight of the small diffuser panels in an array on the rear wall above the couch, staggered at two different depths to help the diffusers act in time as well as space. Budget permitting, an additional four to eight modules may be placed on the same wall, beside the tracking area to help cut down flutter echo between the two parallel walls, while keeping the option of tracking in a more live space.

Two hinged pairs of the dual-sided gobo module will live against the wall beside the doors on the desk's side of the room. These will be deployed during critical listening to create a reflection-free-zone by deflecting sound that would normally bounce off the side walls back to the listening position (if not absorbed by the panels on the doors). Sound from the speakers will be deflected on an angle toward the rear of the room, where the diffusion array will further scatter the sound throughout the room. When not in use for critical listening, these will also be available for any typical studio gobo uses, including helping to isolate musicians and tune the liveness of the space during tracking. They'll also look freakin' great in our living room and my wife will love them.

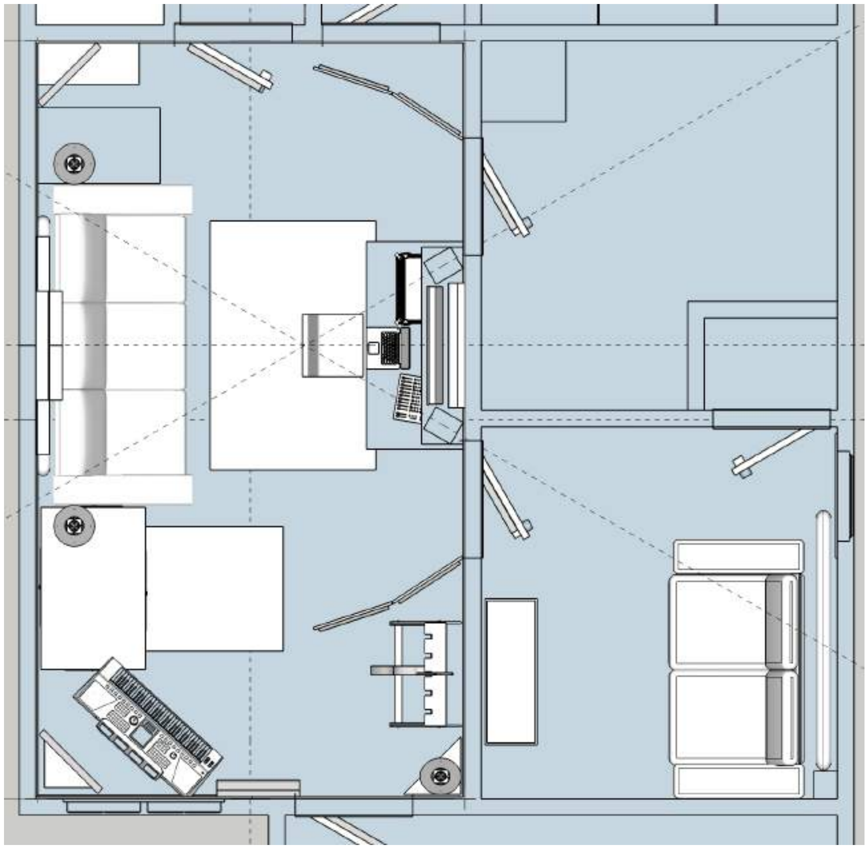
Final Interior Acoustic Design

I say “final” because this is the design I’m submitting. Through this process, I’ve learned a great deal, much of which finally clicked as I was compiling and editing this package. Because I’m creating this design at a time when resources to execute it are less accessible, I will likely continue iterating the design of this space “in the box” and testing the treatments I can apply. I will certainly apply what I’ve learned to making an enjoyable home theater space out of what is currently a spare room with 6 cheap speakers in it. When this difficult time is over, I’ll keep building and testing modules, because it’s fun and I know I’ll be trying to make studios out of many rooms for some time to come.

The following photos are representative of my design based on the above acoustic modules, and my submission will also include a native SketchUp file, including the module components. Following this section, there will be a brief “results” section sharing before-and-after measurements of my listening position with the treatments that I was able to apply, as well as a schematic design of my studio electronics systems.



Acoustic modules



Living room studio, plan view, ceiling cloud excluded.

Living room studio, overview, perspective projection

Bathroom Door POV

Entryway Door POV

Close-up on tracking/instrument area.

Close-up on control area

Couch POV

Desk POV, looking back


POV from Kitchen door

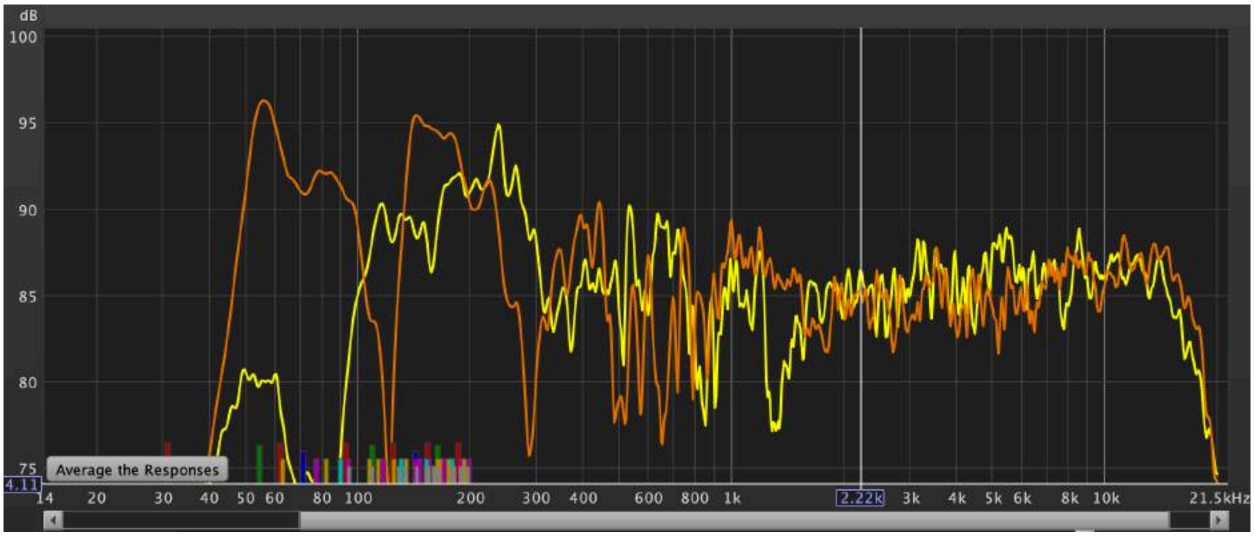

POV from window

Fisheye view of living room studio

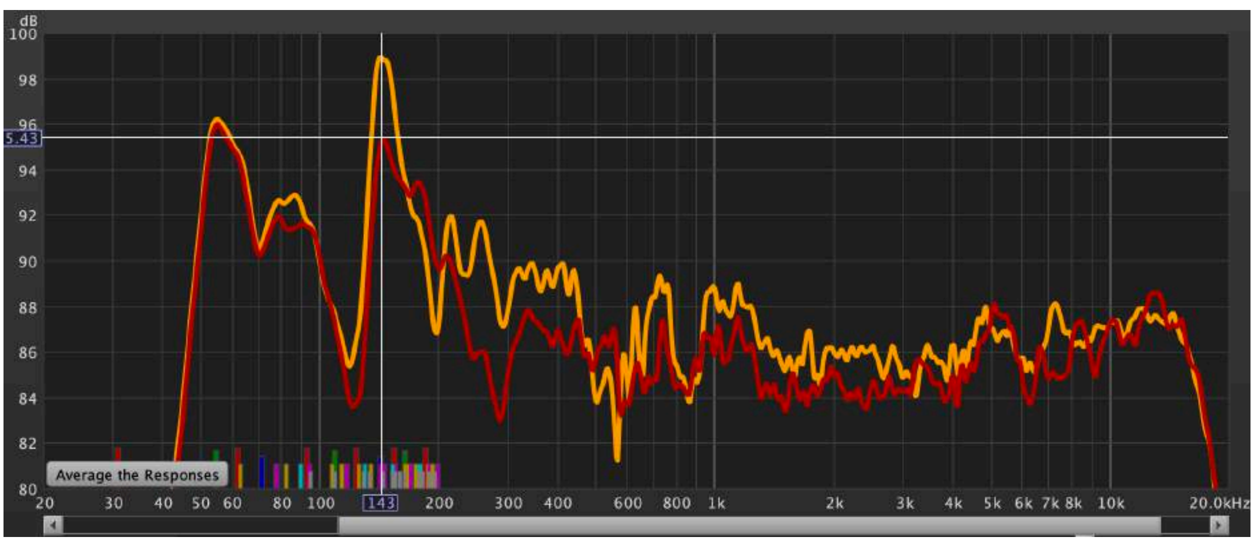
Living room studio, fisheye overview

Section 6: Results

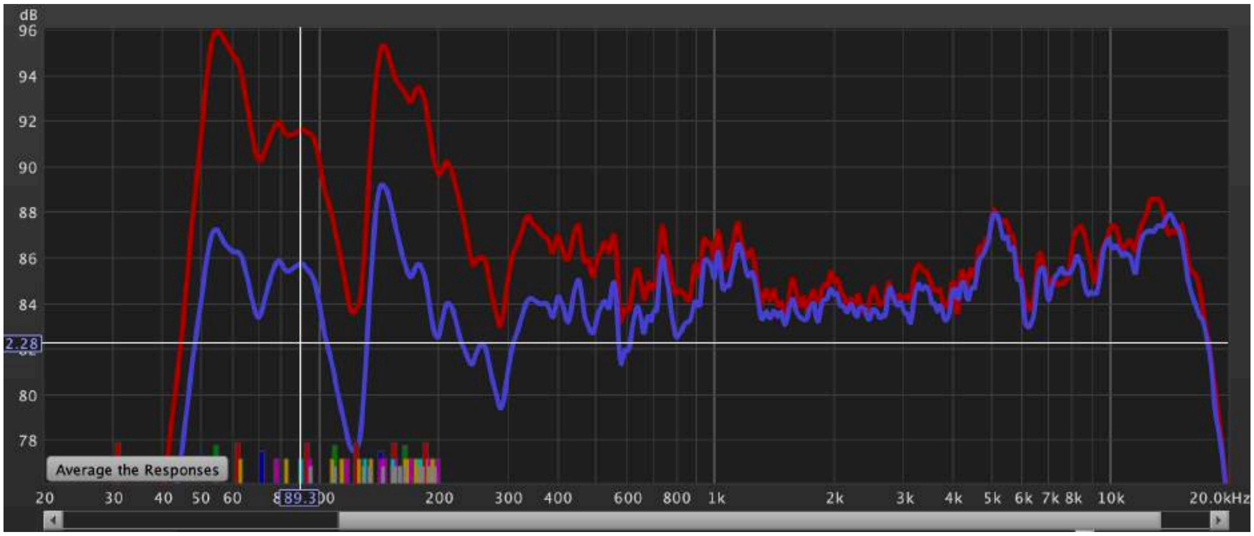
The following measurements compare the room response at the listening position before moving, after moving to the new position, after applying absorption treatment and some monitor adjustments at the new position, and after applying adjustments and DSP at the new position. Tests show a marked improvement from where we started and highlight the progress to be made upon applying a complete design. The only modules completed and available to test with were broadband absorption modules, so tests were done with those, along with environmental treatments such as opening and closing doors.



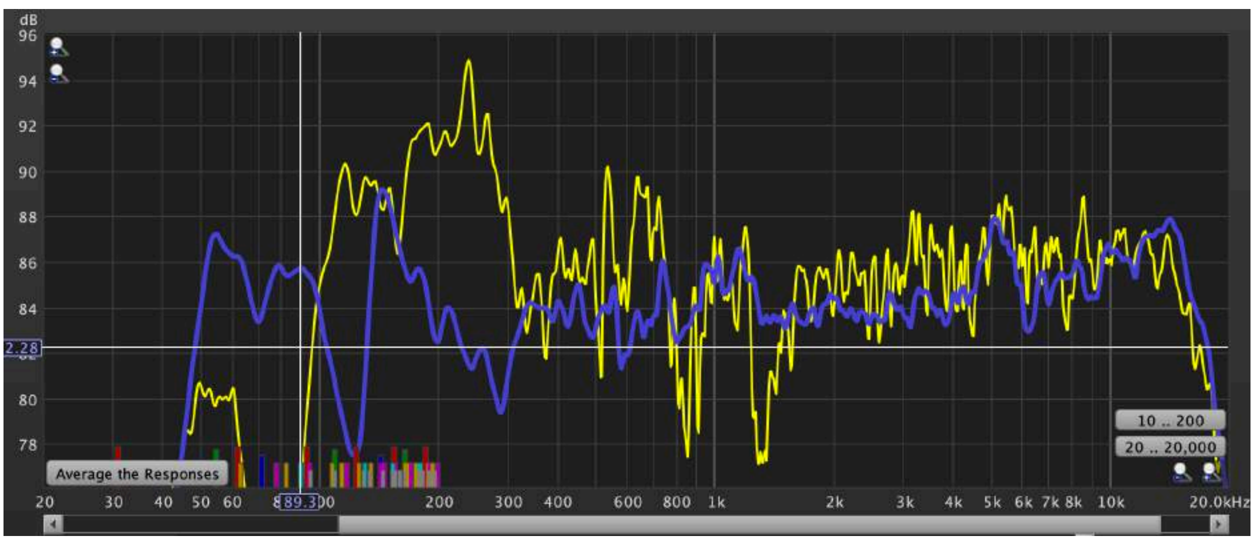
Single sweep frequency response measurements: new listening position (orange) response vs. old (yellow). Notice slightly reduced comb-filter response from 1K up. Comb filter other reflection issues persist in the 300-1K range, and modal issues persist, perhaps even more prominently, below 300.



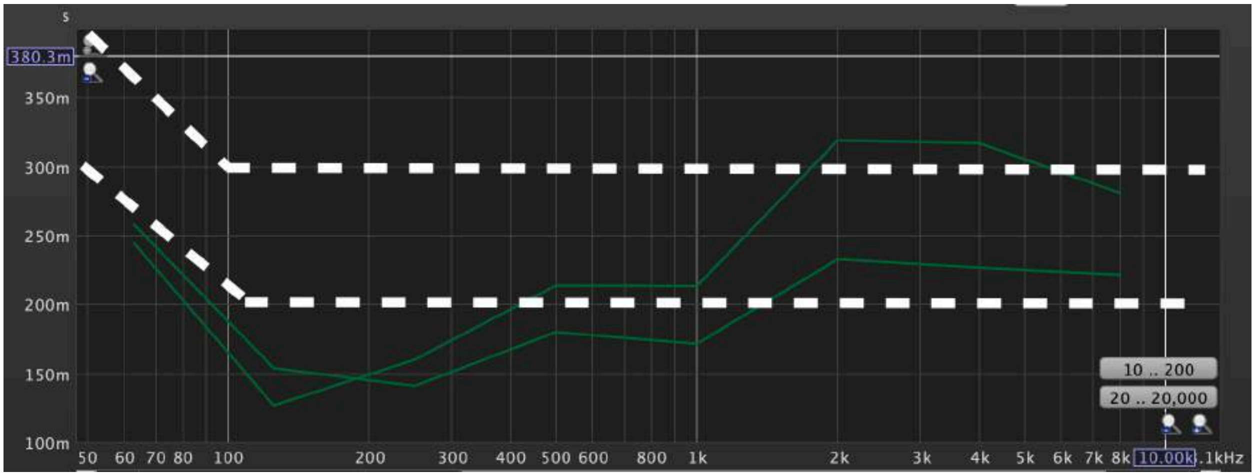
Averaged multi-position measurements at new listening position. No treatment vs. final absorption treatment. Note the flatter response throughout the range from 400-4K Hz. Note the *peak at 143 Hz has been reduced about 4 dB, with only corner-straddling velocity absorbers for low end treatment. The peak at 85 Hz is also notably reduced.*



Final treatment condition before (red) and after (violet) applying two filters of parametric EQ to the low end to reduce modal peaks. The response range is now within about 10-12 dB from 50Hz up, not perfect by any means, but significantly better than the massive 25 dB differences seen in the old listening position.



Old listening position response (yellow) vs new position with basic absorption treatment and EQ applied (violet).

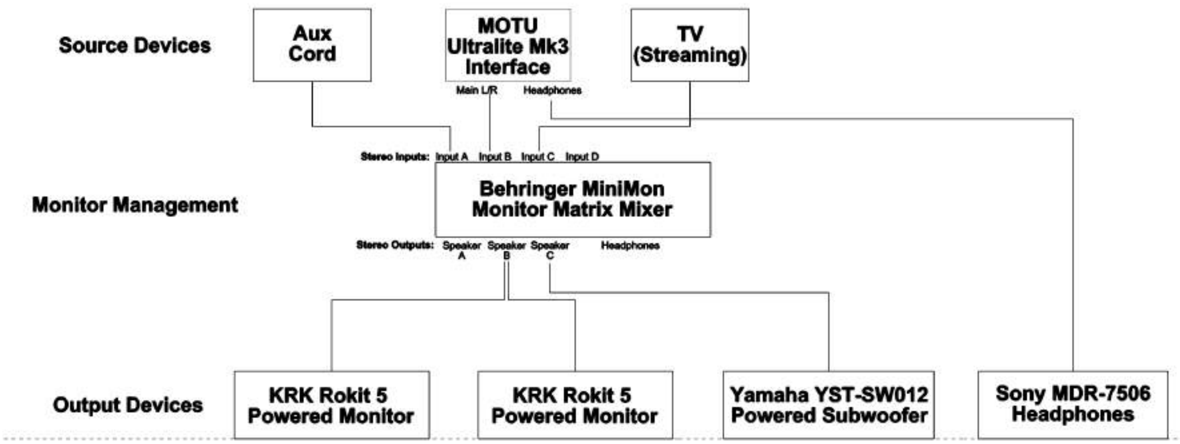


Estimated RT60 via REW's Topt algorithm, before and after treatment. Room decay is now somewhat more consistent, with high end decaying within the target time range and low end below the target range. This is an acceptably tight room for my needs.

Aside from all measurements, my subjective experience of my listening position has improved a hundredfold. Stereo imaging is far better in the latest iteration than ever before, and I find I'm able to listen to music at louder volumes comfortably, while also being able to listen quietly and continue to hear more nuance. I'm hearing details in my reference tracks that I hadn't ever heard on these speakers before. If that's all I ever get out of this, then it was worth it. Thank you!

Section 7: Systems

Monitor System Components, Signal Flow, and Processing



Above is my monitoring system plot. My MOTU interface feeds the KRK monitors and Yamaha sub via a Behringer monitor mixer. The interface also feeds monitor headphones. These are all preexisting components that I'm familiar with and comfortable working on. The MOTU has built in DSP mixing and processing, which is how I apply EQ to my monitors for critical listening, on the input side of the monitor mixer. The monitor mixer can easily incorporate multiple sources and outputs. For example, the monitors and sub are ganged together on one master volume, but can be muted independently, and summed to mono, which are handy features for checking the mix and appeasing neighbors. My speakers are certainly low-end, but they work comfortably for me. The sub has a built-in crossover.

In the future, there are some additions I would like to make to my monitoring: I would like to incorporate an alternate set of 8-10" monitors for full-range listening, as well as DSP EQ and crossover inline to each of the speakers. Something like the MiniDSP 2x4 HD would be perfect for my current set of speakers, though I would lose the ability to easily mute each speaker's signal independently and would have to keep a control MiniDSP program running on the computer or find another way to do that.

Because my listening position serves double duty as living room TV, the display and speakers are also occasionally used for entertainment viewing and listening. Thus, the monitor mixer takes input from not only my studio audio interface (which can be EQ'd), but also from the TV for streaming home entertainment, and from an 1/8" aux cord for miscellaneous other inputs. Neither of these inputs for home use currently benefits from any EQ correction.

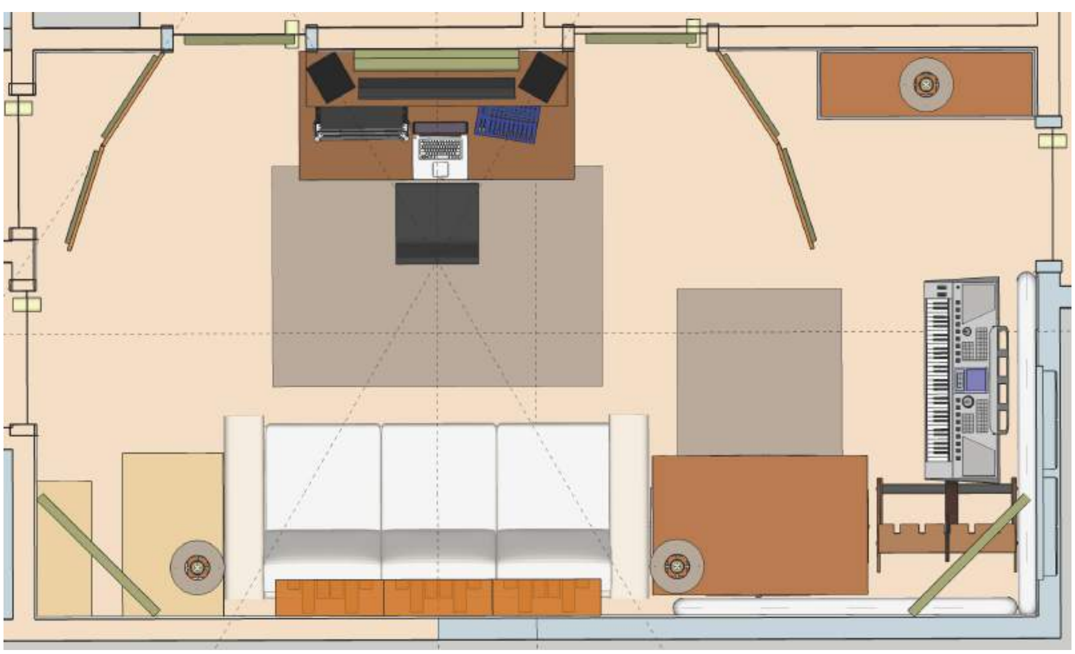
Speaker Placement

My KRK monitors are now moved up from the surface of the desk, upside down, to where the tweeters are at ear level, and have been spaced apart to form an equilateral triangle with the listening position, as far back as possible on their mount above the desk. They can still create a bounce off of the desk surface, but they are much improved from the old furniture arrangement.

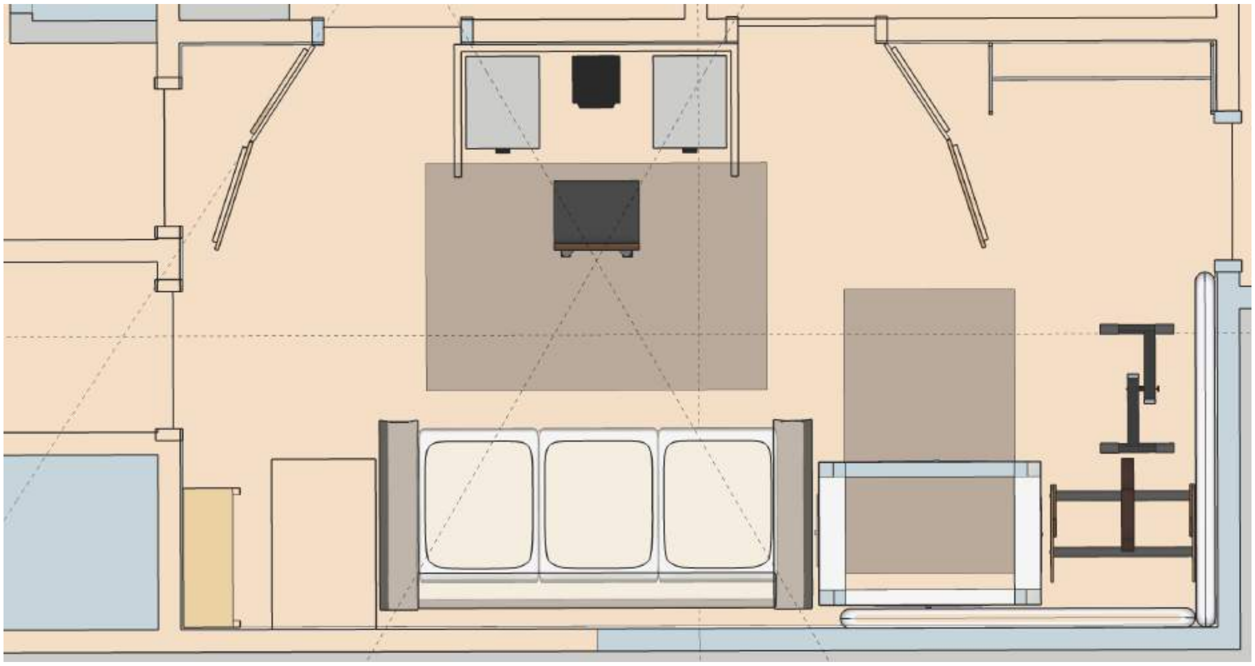
The sub is placed on the floor under the desk, on the centerline of my listening position, which is not the modal centerline of the room. In choosing to place the sub, I used the modal principle of reciprocity: I placed it at ear level at my listening position, and listened to playback from each of the possible positions for the sub. The under-the desk position provided the tightest and most consistent response.

Both the monitors and the sub are decoupled with acoustic foam isolation pads.

Front section showing monitor and sub positions



Plan view showing monitor positions, ceiling cloud and sub excluded



Plan view showing sub position

Side section view showing monitor position, 2" absorber panels seen beside it are between the two speakers, behind the display.

Section on the listening position centerline, showing the sub position.

Full component list and equipment statement

Components:
1 - 13” MacBook Pro
1 - MOTU Ultralite Mk3 Interface (10x12 Interface with 2 Mic Pres, 8 Analog Ins/Outs, stereo SPDIF I/O, Headphone Out, and DSP Mixing)
3 - Presonus BlueTube DP dual channel hybrid tube/solid state preamps (6 ch. total)
1 - FMR Audio RNC1773 Stereo Compressor
1 - Soundcraft Notepad 124 audio mixer
1 - Behringer Minimon Monitor Matrix Mixer
1 - 36-point TRS patchbay
2 - KRK Rokit 5 Nearfield Monitors
1 - Yamaha 10” Sub
Various mics, instruments, and USB MIDI controllers

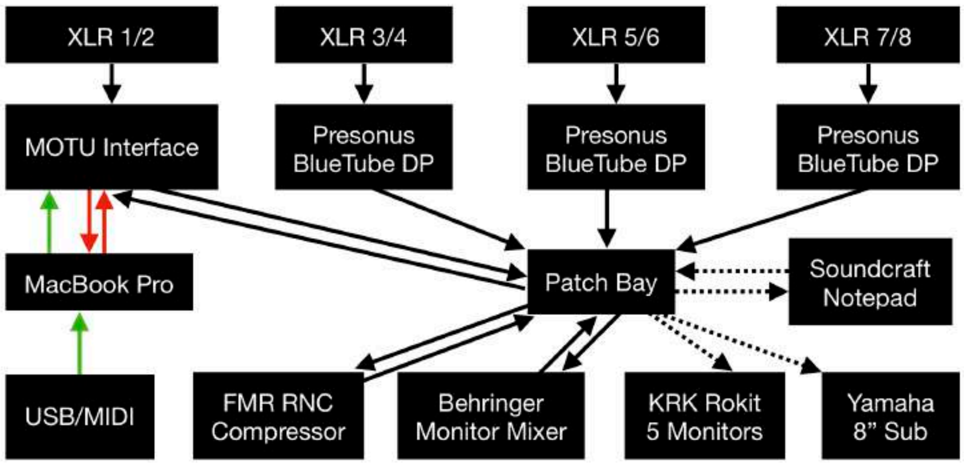
System and Equipment statement

I’m working from components I already have, which I’ve largely accumulated by jumping on exceptional deals on the types of components I need. My entire I/O and monitoring rack has cost me only around $500, including cable, etc. Monitors and sub were had for another $150. The setup works either with my own older MacBook Pro or with my slightly newer MacBook Pro from work, and I also maintain a complete, bootable operating system and set of software on a portable hard drive, so in case of computer failure or other reason, I can quickly be up and running on any Mac. The six half-rack components plus the patch bay in the rear make for a lot of gear in a small package. This layout meets my needs as a complete, flexible, minimalist system where the entire I/O setup stays together in one portable shoulder bag rack, ready to go to record on location in a rehearsal or performance, or for my life where I spend several months a year away from home.

I mostly work in the box. Eight simultaneous channels of analog audio has been plenty for my projects consisting mostly of singer-songwriters, recitals, spoken word, and small groups. This is more than enough for me to multitrack a drumset, which is the most I would need at once in an overdubbed rock/pop recording setting. One component I have been considering more is some type of controller to help me mix in the box a little more efficiently. Regarding individual components I have, while my first consideration has always been finding the best deal for components that can do the job, these components fit my workflow pretty effectively. The Bluetube preamps sound pretty good and are versatile with the ability to dial in a mix of the parallel solid state and tube paths in the unit, providing a range of sounds for the space they take up. Likewise the half-rack RNC compressor sounds good in a vocal path, on an instrument or on a bus, and its stepped controls make it reliably recallable. The Behringer Micromon also fits in a half rack space and is super handy. As a monitor controller, it can select between up to four stereo inputs, and also has a built in talkback mic, and mute, dim, and mono buttons. It can also distribute to up to 3 speaker pairs, a tape output, a cue output, and two headphone outs. The MOTU is among the most versatile audio interfaces available in a half-rack form factor, with a lot of I/O, two decent preamps, and amazing low-latency DSP mixing built in, controllable from the computer or the front panel. The DSP mixer is fantastic for mixing headphones, and I’d even be more than happy to mix a small live show with this setup and multitrack it at the same time.

Good, cheap, minimal. Love it.

Full Signal Flow



Legend:

Analog Audio, permanently patched within rack:

Analog Audio, patched externally from patch bay:

Digital Audio:

Digital Control:

Patch Bay Layout

Patch Bay	36 Points	Half-Normal	De-Normalled (Direct)

Patchbay Layout:	Pair 1	Pair 2	Pair 3	Pair 4	Pair 5	Pair 6	Pair 7	Pair 8
REAR IN FROM:	Pre Out 3	Pre Out 4	Pre Out 5	Pre Out 6	Pre Out 7	Pre Out 8	Motu Main Out L	Motu Main Out R
REAR OUT TO:	Motu In 3	Motu In 4	Motu In 5	Motu In 6	Motu In 7	Motu In 8	**MicroMon In A-L**	**MicroMon In A-R**
	Pair 9	Pair 10	Pair 11	Pair 12	Pair 13	Pair 14	Pair 15	Pair 16
REAR IN FROM:	MicroMon Spk B-L	MicroMon Spk B-R	RNC Out 1	RNC Out 2	Motu Out 1	Motu Out 2	Motu Out 3	Motu Out 4
REAR IN FROM:	MicroMon Spk C-L	MicroMon Spk C-R	RNC In 1	RNC In 2	Motu Out 5	Motu Out 6	Motu Out 7	Motu Out 8

Section 8: Thank you

Thank you!